KRASKIN, LESSE & COSSON, LLP
ATTORNEYS AT LAW
TELECOMMUNICATIONS MANAGEMENT CONSULTANTS

2120 L Street, N.W., Suite 520
Washington, D.C. 20037

Telephone (202) 296-8890
Telecopier (202) 296-8893

EX PARTE OR LATE FILED

RECEIVED
DEC 2 2 1998
FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

December 22, 1998

Magalie Roman Salas
Secretary
Federal Communications Commission
1919 M Street NW, Room 222
Washington, DC 20554

Carol E. Mattey
Chief, Policy & Program Planning Division
Federal Communications Commission
1919 M Street NW, Room 544
Washington, DC 20554

Re: In the Matter of the Petition of the State of Minnesota for Declaratory Ruling
CC Docket No. 98-1
Ex Parte filing

Dear Ms. Salas and Ms. Mattey:

This letter is submitted on behalf of the Minnesota Telephone Association ("MTA") in response to new arguments presented in the Reply Comments of the State of Minnesota (the "State"), the letter from Scott Wilensky dated October 23, 1998 on behalf of the State, and to questions raised by the Common Carrier Bureau staff. The following discussion addresses the issues and provides the information identified in Section B of the Suggested Guidelines For Petitions For Ruling Under Section 253 of the Communications Act, FCC 98-295.

1. *What is the statute, regulation, ordinance or legal requirement that is being challenged? Please provide a copy.*

The Agreement between the State, ICS/UCN, LLC (the "Exclusive Contractor") and Stone and Webster Engineering Corporation, dated December 23, 1997 (the "Agreement") sets forth the core of the "legal requirement" at issue in this proceeding. Excerpts of that Agreement were attached to the State's Petition. The State, by its Petition, in effect concedes that the agreement is a "legal requirement" for the purposes of Section 253. The complete Agreement was filed by letter from the State dated February 3, 1998. In addition, the State, the Exclusive Contractor, and LMAC, LLC (as a substitute for Stone & Webster), have entered into a First Amendment to Agreement dated October 19, 1998 (the "Amendment"), a copy of which was attached to Mr. Wilensky's October 23 letter.

a. The Terms of the Amendment .

The Amendment allows the "Company" (e.g. the Exclusive Contractor) to install "conduit or innerducts" along the Freeway ROWs "at Company's option, that is separate and distinct from, collocated with, and installed concurrently with Company's installation ... ." (Amendment Section 1(c) at page 2)

No. of Copies rec'd 0+2
List A B C D E

The Amendment also allows subsequent installation of fiber optics within the conduits or innerducts, reading in further part:

> Fiber optic cable need not be installed concurrently if it can subsequently be pulled or blown through an existing sheath, innerduct or conduit either (a) without physical entry of personnel or vehicles onto Right of Way or (b) at a location away from traveled lanes or Right of Way (e.g. rest areas, interchanges) and without disrupting or otherwise impairing the safe use of such traveled lanes, as determined by MnDOT … .

(Amendment Section 1(c), page 2). The Amendment was intended to facilitate the Exclusive Contractor's installation of a system that included two(2) separate, rigid 2 inch PVC conduits in the 175 mile Freeway ROW between St. Cloud and Fargo/Moorhead. At this time, installation by the Exclusive Contractor is well under way in this 175 segment of Freeway ROW. The two 2 inch rigid conduits could accommodate multiple installations of fibers, at subsequent times not tied to Exclusive Contractor's schedule.

b. The Significance of the Amendment and Installation Under the Amendment.

The State has requested that "this change [the Amendment] not impact the Commission's determination on the underlying Agreement." (Mr. Wilensky's October 23, 1998 letter) Contrary to that request, it is essential that the Commission consider both the Amendment and the installation of conduit that has already occurred under the Amendment. The Amendment clearly demonstrates that the Agreement can be amended and that the State recognizes and accepts installation of a technology (a multiple conduit system) that can accommodate multiple owners of fibers and installation of fibers at later dates not tied to Exclusive Contractor's construction schedule. The installation of conduit that has occurred shows just how little traffic impact results from installation of fiber optic facilities in wide, lightly traveled rural Freeway ROWs which represent most of the Freeway ROW mileage in Minnesota.

Unfortunately, both Mr. Wilensky's letter and the Amendment reflect the State's continued refusal to require or to take readily available steps to minimize the anticompetitive effects of the State's effort to trade use of Freeway ROWs for free telecommunications capacity for its own use. The State has made no accommodation for subsequent, periodic plowing of fiber or facilities, despite the demonstrable absence of any adverse impact on safety of the current or other fiber facility installations. The Amendment contains no requirement that the Exclusive Contractor install conduit or innerducts in other 1000 miles of the Freeway ROWs and no enforceable standards for the supervision of fees to be charged by the Exclusive Contractor for use of any additional conduit.

Identify and describe any other pending court or state regulatory actions relating to the enforceability of the challenged statute, regulation, or legal requirement.

MTA instituted in State District Court in Ramsey County, Minnesota a civil action, # 62-C8-98-5736 challenging the legality of the Agreement under State law. No claims have been asserted in that action under the Federal Telecommunications Act. In that civil action, the MTA has argued that neither the Minnesota Departments of Transportation ("MnDOT") nor Administration ("MnDOA") have any authority, under either the Minnesota constitution or under Minnesota statutes, to grant exclusive use of Freeway ROWs and that MnDOT violated its own rules in doing so. Trial of these state law issues is scheduled for the week of February 9, 1999.

2. *What specific telecommunications service or services is the petitioner prohibited or effectively prohibited from providing?*

The Agreement effectively prohibits the telecommunications carrier members of Petitioner from using their own facilities to provide: 1) competitive local exchange service in cities located along the Freeway ROWs in Minnesota; and 2) long distance services in and between cities located along the Freeway ROWs in Minnesota; and 3) other high capacity transport and long distance services between those cities and to other providers that need interstate capacity that may traverse these Interstate Freeway routes.[1] The prohibition arises because competitors to the exclusive grantee are prohibited from constructing their own facilities along the most cost effective routes, thus guaranteeing the Exclusive Contractor a major cost advantage.[2]

The use of highly centralized switches linked by high capacity fiber networks to multiple local communities is a critical element of the network architecture of the most viable strategy for providing competitive local service to second, third and fourth tier cities. The Freeway system in Minnesota links the Minneapolis/St. Paul Metropolitan Area to approximately 70 cities, including Duluth, St. Cloud and Moorhead, with populations of 84,000, 50,000 and 32,000, respectively. Many actual and potential competitors of Exclusive Contractor will be effectively prohibited from using their own facilities to provide competitive local service to these cities since those competitors will face significantly higher costs than Exclusive Contractor, which may discourage any attempt at competition. As Mr. Knuth's Affidavit demonstrates, the cost disadvantages of using alternate routes range from 30% to 40%.[3] While these competitors could lease fiber optic facilities from Exclusive Contractor or face the higher installation costs of using alternate routes, the Act clearly did not intend that competitors would be so impeded or disadvantaged in their choice to use their own facilities.

The importance of owning transport facilities to local competition in small cities is underscored by the fact that it is McLeod Telecommunications Inc. ("McLeod") that will be installing its own facilities pursuant to the Amendment. (Amendment Section 3(a)(ii), page 11). McLeod has a well known and well documented strategy of using its own fiber optic facilities to linking many small cities to a small number of centralized switches. McLeod has long had the strategy of "focusing on small and mid-sized markets.[4]" It has formed the "first super regional Competitive Local Exchange Carrier.[5]" It has done so by owing and using an extensive fiber optics network to connect customers from throughout its service area to only few centralized switches. As of October 12, 1998, McLeod was providing competitive local service in 14 states, "with 7 switches, 344,000 local lines, ... and nearly 5,600 miles of fiber optic network.[6]" McLeod has substantial financial resources, reaching $267 Million in revenues, with assets of $1.345 Billion and net

---

1 See, MTA Opposition, p. 26; PUC of Texas, para. 74; New England, Para. 20

2 See, Strategic Policy Research, Response to State of Minnesota Reply Comments, December 22, 1998, attached.

3 Affidavit of Kenneth D. Knuth, November 23, 1998. Attached

4 www.mcleodusa.com, McLeod Mission Statement

5 Id., McLeod Press Release, Oct. 30, 1997.

6 Id.,McLeod Press Release, Oct. 12, 1998.

worth of $559 Million in 1997[7].

McLeod has both the capital resources and the current business plan that enabled it to install facilities to match Exclusive Contractor's installation timetable. While this is beneficial for one local competitor, McLeod, there is no basis in either the Act or in policy to eliminate the same opportunity for either other small existing competitors that may not have the same resources or for future competitors. The strategy of using fiber optics to connect centralized host switching with remote units is a strategy that many other, smaller competitors in Minnesota and elsewhere could also follow, unless prevented by the discriminatory and unlawful restrictions, such as the Agreement. Unfortunately, that is just what the Agreement will do for the next ten + years.

a) *What other specific entities, if any, are prohibited or effectively prohibited from providing the service?*

The record shows that Competitive Local Exchange Carriers, interexchange carriers, cable television providers and wireless service providers all believe the Agreement will effectively prevent them from providing service.[8]

b) *What group or groups of actual or potential customers are being denied access to the service or services?*

The customers most directly and adversely affected will be those in the second, third, and fourth tier cities along the Minnesota Freeway ROWs which will have fewer choices and fewer facilities based providers than they would otherwise have. Many of these cities are too small to justify the cost of indirect routing that would be required of a competitor that wished to provide a facilities based competitive offering through ownership of its own facilities. While such a competitor could obtain facilities from the Exclusive Contractor, such a limitation on a competitors' choices is not what the Act contemplated.

3. *What are the factual circumstances that cause the petitioner to be denied the ability to offer the relevant telecommunications service or services?.*

a) *Does the statue, regulation, ordinance, or legal requirement categorically ban provision of a telecommunications service?*

The Agreement does not contain a categorical ban on providing services, but it does contain a categorical ban on installation on later installation of competitive facilities along the freeway ROWs.

b) *Does the ... legal requirement have the effect of prohibiting the ability of an entity to provide a telecommunications service?*

---

7 Id.McLeod Annual Report, Dec. 31, 1997

8 See, comments cited in MTA Reply Comments, p.3

1) How the ... legal requirement ...has the effect of prohibiting the ability of any entity to provide any interstate or intrastate telecommunications service.

The ban on later installations imposes an effective barrier to competition by imposing very significant extra costs (30% to 50%) on any potential competitor that wishes to use its own fiber facilities to establish connections between communities along the freeway ROWs in Minnesota. The Agreement thus has the effect of prohibiting the ability of other entities to provide interstate and intrastate telecommunications services. As more fully explained in other materials previously filed and from Mr. Knuth's Affidavits accompanying this letter, those higher costs will result from the legal requirement that competitors' use indirect routing on other trunk highways.

2) Whether the [legal requirement] does so in a discriminatory manner.

It apparent that this requirement is discriminatory. The Exclusive Contractor's access to freeway ROWs will receive a material benefit from the cost advantage it receives from the state. The State's refusal to allow periodic installation of fiber facilities or even to require a multiple conduit system clearly shows that the Agreement was primarily intended to grant a competitive advantage to Exclusive Contractor in return for free capacity for the State. Obtaining free capacity is not an objective that will justify the creation of a competitive barrier.

3) Whether price levels in the market preclude recovery of any such additional costs.

Cost differences of 30% to 50% can not be overcome in either the market for competitive local services or in the inter-city wholesale transport market, because price comparison is among the most significant criteria of customer choice. Local competition in second, third and fourth tier cities is expected to be difficult because of the high costs of providing service and the relatively small markets available. When the even greater reliability and decreased risk of damage to facilities resulting from facilities located on Freeway ROWs are added to lower costs, the advantages to the Exclusive Contractor cannot be overcome by competitors. In such a situation, imposing a significant cost disadvantage on other competitors will discourage any competitive entry.

High capacity wholesale transport services and high capacity bandwidth are very much "commodity" services. In such a market, a 30% to 40% cost disadvantage is unlikely to be overcome by other competitors. The greater physical security and resulting greater reliability of a Freeway ROW installation make that advantage all the more overwhelming. While the State argues that the opportunity to use the Exclusive Contractor's facilities (i.e. the State's "carriers' carrier" concept) justifies the competitors' cost disadvantages, such manipulation of the market is far from the open choice of how to compete that Congress intended and that the Commission has recognized.

4) Any other factors that demonstrate that the challenged ... legal requirement has the alleged effect.

An additional concern arises from the fact that neither the Act nor Minnesota Statutes grant to MnDOT or MnDOA any authority to set telecommunications policy or to pick competitive winners and losers. Indeed, it is clear that neither the Minnesota Legislature nor the Minnesota Public Utilities Commission has had any role in this decision by these two administrative agencies.

5) Have other governmental entities adopted similar requirements?

Since the passage of the Act, no other State is known to have adopted such a discriminatory approach to use of freeway ROWs. Many states, including Iowa, Texas, Ohio and Illinois, allow multiple installation of fiber optic facilities on Freeway ROWs. Even states that limit physical entry into Freeway ROWs, typically addressed that concern by requiring installation of multiple conduit systems along the freeway ROWs so that subsequent telecommunications service providers would be able to install their own fiber facilities.[9]

Second, data shows that construction along regular highways is more hazardous than construction along freeways. (Affidavit of Arnold Kraft). If MnDOT's safety argument to prevent installations along Freeway ROWs is accepted, the Commission should be aware that more compelling arguments can be made that installation along regular highway should be curtailed.

6) Assuming the Commission determines that modification of the challenged ...legal requirement is required, what is the least intrusive action necessary to correct the alleged violation of Section 253?

The FCC need not provide specific direction to the state as to how to procure telecommunications service, how obtain compensation for use of its rights of way, or how best to promote safety on the highways. The Commission must, however, enforce the statutory requirements that all such activities be accomplished on a competitively neutral basis. The Commission is neither required nor allowed to accept a claim from a state highway department that public safety can only be achieved through grant of a state monopoly on the most cost effective ROWs, where that claim is neither rational on its face, nor supported by most authorities in that field. The least intrusive action necessary therefore would be to advise the State that its regulation of the use of state ROWs must be done in a manner that reasonably accommodates all competitors up to the capacity of the ROW.
(Re: Sec. 253(b)

2 *Is the challenged...legal requirement:*

(b) necessary to protect the public safety and welfare and does it do so in a competitively neutral and nondiscriminatory manner?

The requirement is neither necessary nor competitively neutral. MnDOT has repeatedly asserted that its primary consideration is ensuring the safety of the traveling public. Public safety <u>is a valid objective</u> under Section 253. The State has also admitted, however, that it sought to maximize the amount of free capacity that it obtained from granting exclusive use of the freeway ROWs. Maximizing free capacity, particularly at the expense of competitive neutrality, is not a valid objective of Section 253.

MnDOT has repeatedly asserted that the safety of the traveling public cannot be assured unless installation of fiber optic facilities along the freeways occurs only once within the next ten years. However, MnDOT has admitted that telecommunications facilities, including copper, coaxial and fiber optics, have been installed in the high traffic Minneapolis/St. Paul Metropolitan area since 1974 for traffic control purposes. Since at least the mid 1980's installation of telecommunications facilities by private contractors for MnDOT have occurred "every year or two" throughout the Freeway system in high-traffic Minneapolis/St. Paul Metropolitan Area. (Deposition of Adeel Lari, vol.1, p.p. 96-98 and Deposition Exhibit 1, attached). These installations were not confined to the edge of the ROW; "they're next to the road. They're in the median. They're every place." (Lari Deposition, vol.1, p.144). There is no indication that there have been any injuries or traffic safety problems resulting from this installation. There is also no indication that any traffic injuries or safety problems resulted from AT&T's installation in the I-94 and I-494 ROWs. Given the importance of safety to this proceeding, the absence of any such information from the state strongly suggests that no injuries and no safety or traffic problems occurred in connection with either the traffic control installations or the AT&T installation. There is no reason to expect any more difficulties with the use of Freeway ROWs by other parties..

A study by the American Association of Highway and Transportation Officials ("AASHTO") also concluded that:

> "One concern is that the utility work will be an unexpected intrusion into the motorist's uneventful travel on the freeway. In reality, there is so much normal highway maintenance throughout the freeway system that the average motorist has come to expect work areas along the road and will hardly notice an occasional utility crew, provided that adequate warning signs are correctly posted."

(Attachment to Kraft Affidavit). MnDOT is a member of AASHTO and had that study available when it filed its comments in this proceeding. The State's fears of the risks of fiber installations off of the traveled roadway are unsupported by the State's own experience with installation in the Minneapolis/St Paul Freeway System and contradicted by the AASHTO Study.

Further, the multiple conduit system now being installed in the Freeway ROW between St. Cloud and Fargo/Moorhead confirms that the concerns of the State have been greatly exaggerated. Arnold Kraft, a certified highway safety consultant with over 30 years of experience, evaluated the construction taking place in the Freeway ROW between St Cloud and Fargo/Moorhead based on photographs taken of that construction. (Kraft Affidavit). Those photographs show:

1. that the rural freeway ROWs are much wider and far less congested than urban Freeway ROWs;
2. that the installation does not and need not occur on the traveled surface of the Freeway ROW or even on the shoulder;
3. That the installation typically occurs 50 to 90 feet from the shoulder;

4. That the construction activities were so inconsequential to the flow of traffic that no MnDOT traffic control engineers were present at the construction site, which is a precaution that is frequently required; and
5. That the construction activities did not cause "gawkers slowdowns" and had no impact on the flow of traffic.

Further, Mr. Kraft notes that routine maintenance operations that occur with regularity along freeways, including cleaning, patching and repair of traveled surfaces, cleaning of freeway signs, maintenance of overpasses and snow removal, all pose substantially greater risks than construction off of the traveled right-of-way.

Minnesota's Procedures for Accommodation of Utilities on Highway Right of Way (which includes freeways), which the State adopted in 1990 contemplated multiple installations upon payment of the established fees, although the State reserved the ability to require installation of multiple conduit systems. (Exhibit 7 to the MTA Opposition, pp.13-14).

The minimal safety impacts resulting from installation of the conduit system demonstrate that the State could establish a schedule that would allow annual or biannual plowing of fiber facilities, under carefully controlled circumstances, that would clearly not impair public safety. The current installation is proceeding without any safety impacts even though MnDOT is not exercising the level of supervision that it would typically apply to a private contractor. There is absolutely no indication that a single opportunity for the next 10+ years is the maximum that can be allowed, unless the goal is to advance the State's economic interest. In areas where there was insufficient space to allow additional plowing of fibers, a multiple conduit system could be required. The multiple conduit system approach reflected in the Amendment would not be adequate even where the ROW space was limited because the Exclusive Contractor is not required to install a multiple conduit system and because the Amendment does not establish an adequate mechanism for assuring that access to that system may be available to competitors at reasonable costs.

In the face of this evidence, it is apparent that the onerous restrictions imposed by MnDOT on fiber installations in rural portions of the freeway ROWs are unrelated and unnecessary to safety considerations. Rather, such restriction can be understood only in the context of MnDOT's goal to maximize the free capacity to be provided to the State. While that may be a goal that MnDOT and MnDOA find to be of the utmost importance, it is not a valid objective of Section 253 and certainly provides no justification for discriminatory legal requirements.

For these reasons, the Minnesota Telephone Association submits that the proposed Agreement is an unlawful barrier to competition under Section 253(a) because it has the effect of prohibiting competition in communities located along Freeway ROWs in Minnesota. That barrier is not justified under either Section 253(b) or (c) because the maximization of free capacity for the State is not an objective that justifies such a barrier and because the restrictions are neither non-discriminatory nor necessary to achieve public safety or to management of the ROW. Accordingly, the Commission should preempt the Agreement., Very truly yours,

MINNESOTA TELEPHONE ASSOCIATION

By: Richard J. Johnson (DC)

Richard J. Johnson

Moss & Barnett, P.A.
4800 Norwest Center
90 South Seventh Street
Minneapolis, MN 55402-4129

David Cosson
Kraskin, Lessee & Cosson, LLP
2120 L Street, N.W., Suite 520
Washington, D.C. 20037
202 296 8890

Attachments
Strategic Policy Research Response
Affidavit of Arnold Kraft
Affidavit of Kenneth Knuth

CC with Attachments Claudia Pabo
RJJ/rmw

STRATEGIC
POLICY
RESEARCH

7500 OLD GEORGETOWN ROAD SUITE 810 BETHESDA, MARYLAND 20814 (301) 718-0111 (301) 215-4033 fax
EMAIL spri-info@spri.com

EX PARTE OR LATE FILED

Response to
State of Minnesota Reply Comments

Margaret L. Rettle
Harry M. Shooshan III
Joseph H. Weber

for the
Minnesota Telephone Association

CC Docket No. 98-1

December 22, 1998

Strategic Policy Research ("SPR"), engaged by the Minnesota Telephone Association ("MTA") in this proceeding, has reviewed the State of Minnesota's ("the State") *Reply Comments and Opposition to Request of the Minnesota Telephone Association, et al. for Preemption* (hereinafter *Reply*). In its *Reply*, the State responds to a number of points made by SPR in our original Affidavit on behalf of MTA. Here we respond to the State's comments and those in the attached affidavits as they relate to our Affidavit and to the appropriate market analysis in this proceeding.

Our response is structured along six subject matters: (1) the relevant market; (2) the fiber supply in Minnesota; (3) the availability of alternative rights-of-way; (4) conferring market power on the Developer; (5) the effect of the Agreement on competition; and (6) balancing safety and competitive neutrality.

Relevant Market

The State re-iterates its position that the relevant market for analysis in this proceeding is the wholesale fiber capacity throughout the State.[1] State witness Alan Pearce went much further in his affidavit, claiming that the relevant market is so large as to include "the provision of transmission capacity for telecommunications-information-entertainment" throughout the State of Minnesota. He concludes that the State's definition is, therefore, "extremely conservative."[2]

Pearce's market definition is implausibly broad and, therefore, has been clearly devised to make the State's definition *appear* conservative. As we stated in our Affidavit, the relevant market is the set of points served by the interstate freeway system in Minnesota. Specifically, we believe that the State must show that there is adequate competing fiber capacity in *each* of the *actual* relevant geographic markets.[3]

The Federal Communications Commission ("FCC") has taken a similar view for purposes of evaluating whether an interexchange carrier has market power on a point-to-point basis, *i.e.*, whether there are alternatives in the market for traffic between two particular cities. The FCC

---

1 State *Reply* at 10.

2 Affidavit of Alan Pearce at ¶ 15.

3 SPR Affidavit at 4-5.

apparently found a national market not useful in such circumstances.[4] The FCC has additionally taken this view in its analysis of international communications markets.[5]

As we discussed in our affidavit, on routes where there is no alternative fiber, the Developer will have market power. Moreover, on routes where there is an abundance of fiber, the economic value of investment in the State's fiber network is questionable, casting doubt on the wisdom of the entire venture.

Fiber Supply in Minnesota

The State, in its *Reply*,[6] as well as in Bhimani's[7] and Pearce's[8] affidavits has provided evidence of what it finds to be an abundant supply of currently available and planned fiber throughout the State of Minnesota. The State appears to have put this evidence forth in response to our assertion that the State "has not provided sufficient evidence that alternative facilities exist or may exist in ten years between all of the points served by the interstate freeway system in Minnesota."[9]

The State's evidence is conflicting. Attachments, B, C and D to Bhimani's affidavit purport to indicate an adequate supply of fiber in the state of Minnesota. While Attachment B demonstrates the presence of MEANS' large fiber ring connecting the major cities of the State, this ring does not necessarily parallel the freeway rights-of-way, as Bhimani claims.[10]

---

4 *Regulatory Treatment of LEC Provision of Interexchange Services Originating in the LEC's Local Exchange Area and Policy and Rules Concerning the Interexchange Marketplace*, CC Docket Nos. 96-149 and 96-61. *Second Report and Order in CC Docket No. 96-149 and Third Report and Order in CC Docket No. 960-61* (rel. April 18, 1997) at ¶¶ 64-69.

5 *International Competitive Carrier Policies*, CC Docket No. 85-107, *Report and Order*, 102 FCC 2d 812 (1985).

6 *Reply* at 9-11.

7 Affidavit of Fazil Bhimani at 6-8.

8 Affidavit of Alan Pearce at ¶ 17, 18, 22, 26, and 30.

9 *Reply* at 19.

10 Bhimani Affidavit at 6.

Additionally, this fiber ring does not cover the northernmost portions of the State. Attachments C and D demonstrate a similar lack of fiber in the northeast corner of the State.

The most interesting attachment to the State's *Reply* is Exhibit 6, a copy of a recent edition of the MTA monthly newsletter, *Minnesota Telecommunications Guide.* In this newsletter, the director of telecommunications for the Minnesota State DOA, Bill Schnellman, says "there's no high-speed rural network in place." He goes on to say, "This isn't costing the state or local phone companies anything . . . so why not do it?"[11] According to Mr. Schnellman, there appears to be a greater need of facilities in rural areas rather than along the freeways. If there is such a glut of capacity along freeways, as the State claims, it then seems that the State should have contracted for a rural high-speed network.

The State cannot have it both ways. Either there is insufficient capacity along all or some of the relevant routes (in which case the Developer will have market power for a ten-year period), or there is ample capacity on the relevant routes (in which case the investment is questionable, as best). As we discuss below, the terms of the Agreement place the Developer in a position where it enjoys market power.

Alternative Rights-of-Way

State witness Bhimani disputes our assertion that the freeway system represents the most direct and least-cost routes among the major cities. He further provides evidence to suggest that there are minimal cost differences between freeway rights-of-way and alternative routes.[12] Nevertheless, as Pearce notes, many carriers are now negotiating with the Developer to place fiber in the freeway rights-of-way.[13] This desire of parties to install facilities in the previously unavailable rights-of-way is evidence of the economic value of the freeway rights-of-way *vis-à-vis* other routes. As we stated, parties should be encouraged to deploy their facilities in these

---

11 State of Minnesota, Exhibit Six, *Minnesota Telecommunications Guide* (February 1998 No. 3).

12 Bhimani Affidavit at 8-9.

13 Pearce Affidavit at 11.

rights-of-way.[14] We favor encouraging simultaneous installation so that parties may enjoy the benefits of these rights-of-way with minimal disruption, not because we agree with the terms of the Developer's exclusive access.

Conferring Market Power on the Developer

The State claims that its RFP process assures competitive neutrality in the availability of rights-of-way.[15] Pearce goes a step further, comparing the State's RFP process to the FCC's spectrum auctions.[16] Pearce's analogy does not hold. Unlike the FCC's auctions, the State's RFP resulted in a single provider having exclusive access and control over Minnesota interstate freeway rights-of-way for a ten-year period. On the other hand, no PCS licensee, for example, has been granted exclusive control over the supply of PCS spectrum in a single market.

The State disagrees with our position that the contractual duty of the Developer to lease capacity at nondiscriminatory rates suggests concern about the exercise of market power. It further observes that "[n]o party has presented any serious discussion as to why a market that has developed with incredible speed over the past decade without access to freeway rights-of-way will come to a screeching halt and face supply constraints."[17]

The State misses the point. The future of the market may not be dependent upon whether freeway rights-of-way are made available at all, but it is dependent on whether freeway rights-of-way are made available *under nondiscriminatory conditions to all telecommunications providers*. The Developer has been given exclusive access to and control over this right-of-way that has economic value because it uniquely provides the most direct and efficient route between major points in Minnesota. Further, the Developer reserved the right to terminate the Agreement if the exclusivity conditions are not upheld.[18] If the rights-of-way truly have little economic value

---

14 SPR Affidavit at 4.

15 *Reply* at 44.

16 Pearce Affidavit at 14.

17 *Reply* at 22-23.

18 *Ibid.* at 24.

(because there is so much existing capacity), then why was an exclusive arrangement contemplated at all? One is left to ask, "exclusivity against whom?" Clearly, the exclusive right to control the rights-of-way in question is an essential element in the deal and represents a substantial portion of the economic value of the arrangement.

Effect on Competition

The State takes the position that "any entity that does not wish to place fiber [on the State's schedule], or that did not exist [at the time], does not have a right under Section 253(b)'s competitive neutrality principle to force the State to open its rights-of-way at whatever time meets its investment plans."[19] We agree that the State cannot be expected to open its rights-of-way to accommodate each and every individual entity's schedule. We cannot agree that it is reasonable to foreclose access for ten years. This aspect of the proposed arrangement can be expected to have a chilling effect on competition. As we discussed in our initial Affidavit, this lack of flexibility causes carriers to make significant up-front investments that may be economically inefficient. Future entry is inhibited as well by the restrictions in the Agreement.[20]

The State compares its arbitrary limitation of available right-of-way to the capacity constraints in ILEC switches, which, the state suggests, may deny some future competitors the opportunity to collocate.[21] The State's comparison is inaccurate and misunderstands the regulatory environment in which ILECs operate. ILECs would not be permitted to arbitrarily deny collocation while space is available and must provide "virtual" collocation when space is unavailable. The State's position is not predicated on a lack of space. The State has determined that it will deny access to its rights-of-way to all but one entity for a ten-year period. Further, entities that need additional or new capacity between the ten-year intervals will be forced to lease others' facilities. This is not consistent with the 1996 Act's provisions to allow competitors to choose their means of entry: resale, leasing of network elements, and/or construction of their own facilities.

---

19 *Ibid.* at 45.

20 SPR Affidavit at 5.

21 *Reply* at 45.

Balancing Public Safety and Competitive Neutrality

The State cites our view that it is reasonable for it to encourage other parties who *currently need* capacity along these routes to contract with the Developer to install fiber for them at the same time the Developer is installing fiber for the State's use.[22] The State does not go on, however, to cite our assertion that it is *not* reasonable to restrict right-of-way access to a single installation or to require parties to go through a single gatekeeper, particularly the Developer that may also provide service.[23] Our recommendations for balancing public safety and competitive neutrality do not lead to the conclusion that the terms of the State's Agreement with the Developer reasonably balance public safety and competitive neutrality, as the State may imply.

The State argues that ten-year intervals are necessary for public safety.[24] The State is on a slippery slope. If it is so unsafe to provide access to longitudinal rights-of-way *and* if there is an overabundance of capacity near the interstates, then there is no reason to open the right-of-way at all. Once rights-of-way are made available, however, the State must develop a reasonable balance between public safety and private sector interests. If opening rights-of-way every ten years is not detrimental to public safety, then opening them every five or three years, or even once a year may be possible. The State must show that opening the freeways to construction only every ten years is acceptable, but more frequently is not. We accept the point that there is some hazard in such operations. The State must demonstrate, however, the balance between costs and benefits of any installation schedule before embarking on a course which is discriminatory.

Conclusion

The relevant geographic market for analysis in this proceeding is the set of points served along the interstate freeway system in Minnesota. The State's proposed statewide market is unreasonable. Further, Pearce's inclusion of information and entertainment transmission is completely implausible. There may be fiber in the most populated areas of the state, but not in

---

22 *Ibid.*, at 31 and 37.

23 SPR Affidavit at 4.

24 *Reply* at 40.

the northernmost parts, nor in the freeway rights-of-way. The Developer has been granted market power as it has exclusive ten-year access to, and control of, valuable freeway rights-of-way in Minnesota. Competition for wholesale fiber capacity and for retail services is inhibited by the Developer's exclusive access to these rights-of-way. While the State obviously may take reasonable measures to ensure public safety, its Agreement with the Developer does not reasonably balance public safety and private interests.

The State has not met its burden in this proceeding. We recommend that the FCC advise the State that its arrangement constitutes a barrier to entry under Section 253 of the Telecommunications Act of 1996.

I have read the foregoing affidavit and being duly sworn, depose and say that it is true and correct to the best of my knowledge and belief.

Margaret L. Rettle

Margaret L. Rettle

Subscribed and sworn to before me this 22nd day of December, 1998.

Adrienne Wells Vendig

Notary Public

Adrienne Wells Vendig, Notary Public
Montgomery County
State of Maryland
My Commission Expires Sept. 1, 2002

STATE OF MINNESOTA)
) ss
COUNTY OF HENNEPIN)

EX PARTE OR LATE FILED

AFFIDAVIT OF
ARNOLD R. KRAFT

1. My name is Arnold R. Kraft. I am the Principal of ARK Management Associates. I am and have been the chief construction instructor for the Minnesota Safety Council since 1993. I am and have been the Construction Director of the Great Lakes Training Consortium, the Federal OSHA outreach program in Minnesota since 1995. In that position, I am responsible for implementation and training of the OSHA courses for other safety trainers and construction safety personnel, including highway construction in the Upper Midwest. I am and have been a Certified Safety Professional, certified by the National Board of Certified Safety Professionals since 1997. I routinely provide highway and other safety training and instruction for construction contractor organizations such as the Associated General Contractors (AGC), Associated Builders and Contractors (ABC), Minnesota Utility Contractors Association (MUCA), and North Dakota Safety Council. I am a member of the American Society of Safety Engineers, on the Board of Directors of the Minnesota Surveyors & Engineers Society, a member of the Society of American Military Engineers and have served as President and on the Board of Directors of many contractor organizations in the last forty years.

2. I have been involved with highway construction projects for over 40 years and have been responsible for safety relating to highway construction for over 20 years, including construction on both freeway and on other highways in heavy traffic urban areas and in light traffic rural areas throughout the State of Minnesota. I was a Contractor in my own company, M. E. Kraft Co., Inc., a highway construction company from 1960 to 1970. I was Vice-President and General Manager of Acton Construction Company from 1979 to 1982, District Manger for D. H. Blattner and Sons Company from 1982 to 1987, Project Manager for Enebak Construction Company from 1987 to 1989. During this time, I was involved in over 5 major construction and maintenance projects involving freeways in the Minneapolis/St. Paul Metro area, over 4 construction and maintenance projects involving freeways in rural areas of Minnesota, and over 10 construction and maintenance projects involving other trunk highways in the Minneapolis/St. Paul Metro area and in rural areas of Minnesota.

3. Since 1990, I have provided safety consulting service to contractors for construction projects involving both urban and rural freeways in Minnesota and construction projects involving other trunk highways in both urban and rural parts of Minnesota. As a safety consultant, I am involved in assisting highway contractors to create safe working environments for both their employees and the traveling public. My responsibilities relating to highway construction consulting include safety training, safety procedures, safety plans, monitoring and inspection.

4. As a result of my training and experience, I am familiar with safety techniques and with state and federal highway construction standards applicable in Minnesota, including standards applicable to freeway construction in both urban and rural areas.

5. The purpose of my Affidavit is to respond to safety concerns discussed by the State of Minnesota in its Reply Comments and attached Affidavits.

6. On November 23, 1998, I directed one of my associates, Christopher Arlandson, to observe and photograph plowing of the conduit system in the I-94 Freeway ROW. Mr. Arlandson did observe and photograph plowing of the conduit in the I-94 ROW near the Douglas County line northwest of Alexandria, Minnesota. Based on my familiarity with the rural Freeway ROWs in Minnesota, I can confirm that the Freeway ROW photographed is typical of the rural Freeway ROW in Minnesota both in the width of the controlled ROW (the area between the fences, which are typically close to the ROW boundary lines) and with respect to the lack of obstructions on the rural Freeway ROWs.

7. The Agreement between the State of Minnesota and its contractor ICS/UCN, includes a requirement that the fiber be installed "near the right-of-way line, or as determined by the department." (Agreement Exhibit H, including the MnDOT Procedures dated July 27, 1990 , SECTION VI, FREEWAYS; LONGITUDINAL OCCUPANCY, page 11). These terms will require that the fiber be installed close to the control of access fence line, which is well beyond the shoulder and far from the traveled road surface of the Freeway. As a result, there should be no construction or obstruction of the traveled lanes of the Freeways.

8. Mr. Darrel Durgin, Deputy Commissioner/Chief Engineer with the Minnesota Department of Transportation ("MnDOT") cites data from MnDOT and states that "in the last five years, there have been more than 11,000 street and highway work zone crashes in Minnesota." (Paragraph 17 and Attachment B to his Affidavit, attached to the State's Reply Comments). While this may be correct, it combines information from all street and highway situations. There are well recognized differences between the safety implications and the safety requirements of construction depending on whether the construction will be done on or off of road surfaces, in two lane highways or on freeways, and in urban high traffic or in rural low traffic areas. As a result, Mr. Durgin's data obscures and ignores known differences between different types and locations of construction activity and does not provide useful information regarding the specific safety implications of construction beyond the shoulder of rural Freeway ROWs.

9. The differences between the safety implications of construction on the traveled surface of roadways and construction beyond the shoulders of roadways are very clear both from observation and from available data. The National Cooperative Highway Research Program ("NCHPR") published a study of work zones and appropriate speed limits in the Research Results Digest, September 1996 Number 192. (Attachment 1). NCHPR is a research institute sponsored jointly by the American Association of State Highway and Transportation Officials ("AASHTO")in cooperation with the Federal Highway Administration.

NCHPR studied the effects of various construction activities, ranging from Condition 1 (activities more than 10 feet from the edge of the traveled way [i.e. roadside activities]) to Condition 7 (activities that encroach on both sides of a lane line). The 5th column from the right of Table 10 (page 20 of Attachment 1) shows that the rate of accidents during construction on the shoulder or along the roadside of rural Freeway is less (.97 accidents per million vehicle miles) than for construction on the shoulder or along the roadside of rural two lane highways (2.68 accidents per million vehicle miles). The 2nd to last column of Table 10 (on page 20 of Attachment 1) also shows that construction activity on the traveled surface or with detours significantly increases frequency of accidents in all road types, 41.3% with rural freeways, 34.2% with urban freeways, and 46.7% with rural two-lane highways.

The 2nd to last column of Table 10 also shows that construction on either the "Shoulder/Roadside" (i.e. on shoulder or beyond the shoulder) did not increase accident rates in on any road type. The impact of construction on shoulders or roadsides was a 4.3% decrease with rural freeways, a 2.2% decrease with urban freeways and a 5% decrease with rural two-lanes. (page 20 of Attachment 1). This study is consistent with my experience and expectation that the likely safety impact of the proposed installation along the Freeway ROW is very low.

10. The NHCPR study concluded that construction activities located outside of 10 feet of the traveled way (Condition 1) on limited access highways do not merit any reduction in the traveled speed in the area of the construction:

> There should not be a reduction to the existing regulatory speed limit unless unusual situations create hazardous conditions for motorists, pedestrians or workers.

(Attachment 1, page 31). Installation by plowing and/or ditching the fiber optic cable conduit will move steadily and will be far from the traveled surface. An operating plan detailing construction activities and related safety measures should be in place to eliminate conditions that could create any "gawker slowdown". Work done close to interchanges and jacking or boring operations (to cross under bridges or roadways) will require added steps. However, a good safety plan with rules and regulations relating to those conditions, made a part of the operating plan, can and will keep the traveling public and the workers safe. Detailed standards for development of safety plans are published by MnDOT in various manuals that are familiar to highway construction professionals.

11. Mr. Durgin also assumed that construction would require lane closures and discussed that process in paragraphs 17 to 22 of his affidavit and attached a photograph of construction along the New York Throughway, showing a lane closure. There are differences between the portion of the New York Throughway shown in Mr. Durgin's photograph and rural Freeways in Minnesota that will make lane closures unnecessary and even counter productive. Based on comparison of the photograph of the New York Throughway included with Mr. Durgin's materials and typical rural Freeway ROWs in Minnesota, rural parts of Minnesota Freeways appear to carry less traffic and appear to have wider ROWs than the portion of the New York Throughway shown in Mr. Durgin's photograph. See, Photographs 1 and 2.

12. Rural Freeways in Minnesota typically have very wide ROWs.. Photograph 2 indicates that the control of access line is approximately 75 feet from the shoulder on the side where installation is occurring and approximately 60 feet from the shoulder on the other side. As a result, installation of fiber optic facilities along the Minnesota Freeways will occur far from the traveled Freeway surface and lane closures should not be needed.

The attached photographs of recent installation near the Douglas County line in the I-94 Freeway ROW confirm that lane closures are not needed and that there is no disruption of traffic from the construction activities. In most locations, the trench for the conduit was 60 to 70 feet from the shoulder. (See Photograph 2 attached which shows the location of the trench for the conduit.) The trench location is where the installation equipment would typically operate. In one location, the installation was closer, but it was still approximately 20 feet from the shoulder. There was no installation equipment on either the shoulder or traveled surface of the Freeway ROW. It was also apparent that there were no "gawkers" and that there was no slowdown of traffic as a result of the construction activities. (See Photographs 3 through 7 attached).

Two light trucks were parked on the shoulder in the area of the installation. (Photographs 2 and 6). Construction permits for private installations typically require that all vehicles be parked off of the shoulder. If this standard had been followed by MnDOT's contractor, the installation would have been even less noticeable.

Private contractors are also often required to work under the supervision of MnDOT traffic safety engineers. There was no evidence that MnDOT traffic safety engineers were on site at the construction locations. This is not surprising for construction activities in areas beyond the shoulders of rural Freeways.

13. In many ways, plowing of fiber optic cable will be similar to typical ROW maintenance, such as removal of refuse from roadsides, mowing of grass, sign maintenance and replacement, fence repair, and/or culvert construction that occur routinely. It will be less intrusive than repairs to the traveled surface such as joint repair and patching, which are also common in Minnesota and other cold climates as a result of frost damage. It will also be less hazardous than snow removal which is very common in Minnesota. The traveling public may notice the construction activity, but due to the lack of lane closures and the distance away from the traffic, installation of fiber optic cable or conduits should not slow motorists' pace or pose any significant hazard.

This conclusion is confirmed by a study by NCHPR. A 1996 NCHPR research study entitled "Longitudinal Occupancy of Controlled Access Right-of-Way by Utilities, NCHRP Synthesis 224. That study reviewed in likely impacts of utility use of Freeway ROWs. It summarized experience of other States, saying:

> Iowa is completing a 350-mile (563 km) fiber optic line of freeway right-of-way in strict compliance with its policy and has experiences no problems.

(Attachment 2, page 11).The Study also summarized the responses of other states:

> The farther from the traveled way the utility is installed, the less impact there is on the motorist.

(Attachment 2, page 11) The Study also observed:

"One concern is that the utility work will be an unexpected intrusion into the motorist's uneventful travel on the freeway. In reality, there is so much normal highway maintenance throughout the freeway system that the average motorist has come to expect work areas along the road and will hardly notice an occasional utility crew, provided that adequate warning signs are correctly posted."

(Attachment 2, page 12). This is consistent with my prior experience. This is also consistent with the actual results observed in connection with the recent installation on the I-94 ROW northwest of Alexandria.

14. The installation of fiber optic cables, whether by one operator or by a number of operators, will not increase the risk of additional accidents, if the cable operation is installed utilizing proven known safety practices designed to reduce the risk of accidents to the traveling public and the workers. It is my opinion, that the installation of the fiber optic cable can be installed by a number of different operators, if the conditions of construction are controlled as provided in applicable MnDOT specifications and/or Manuals.

Signed Arnold Kraft Date Dec 21, 1998
Arnold R. Kraft

SWORN TO BEFORE ME
this 21st day of December, 1998

Jean J. Hunsinger
NOTARY PUBLIC

JEAN J. HUNSINGER
- MINNESOTA
COUNTY
My Commission Expires Jan. 31, 2000

NCHRP

National Cooperative Highway Research Program

RESEARCH RESULTS DIGEST

September 1996 **Number 192**

These **Digests** are issued in the interest of providing an early awareness of the research results emanating from projects in the NCHRP. By making these results known as they are developed, it is hoped that the potential users of the research findings will be encouraged toward their early implementation in operating practices. Persons wanting to pursue the project subject matter in greater depth may do so through contact with the Cooperative Research Programs Staff, Transportation Research Board, 2101 Constitution Ave., N.W., Washington, DC 20418

Subject Areas: IIIC Maintenance, IVA Highway Operations, Capacity, and Traffic Control and IVB Safety and Human Performance

Responsible Senior Program Officer: Kenneth S. Opiela

Procedure for Determining Work Zone Speed Limits

This NCHRP digest summarizes the findings of NCHRP Project 3-41, "Procedure for Determining Work Zone Speed Limits," conducted by Graham-Migletz Enterprises, Inc. The digest, prepared by Lloyd R. Crowther and Kenneth S. Opiela, NCHRP Senior Program Officers, is an excerpt from the contractor's final report.

INTRODUCTION

The national *Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD)* (*1*) has no uniform guidelines for determining work zone speed limits. Consequently, work zone safety problems are aggravated by (1) inconsistencies in the methods used to determine work zone speed limits, (2) motorist noncompliance with the posted work zone speed limits, and (3) the growing practice of setting work zone speed limits through legislative or administrative decisions without the benefit of an engineering study. At their 1988 joint meeting, the AASHTO Highway Subcommittee on Traffic Engineering and the Maintenance Technical Committee of the National Committee on Uniform Traffic Control Devices unanimously concurred that research was urgently needed to establish a procedure for determining work zone speed limits to address these safety problems. The research reported here was initiated to meet this need.

THE PROBLEM AND ITS SOLUTION

The objective of this research was to develop a uniform procedure for determining work zone speed limits. The procedure had to be widely applicable and to accommodate, to the maximum extent possible, the often divergent interests of motorists, workers, and pedestrians. To meet this objective, the researchers sought to answer three fundamental questions: (1) Are work zones with reduced speed limits safer? (2) What are the compliance levels with various speed limit reductions? and (3) What roadway and traffic factors should be considered in determining a work zone speed limit?

To answer these questions, Graham-Migletz Enterprises, Inc. (GME) conducted a literature review and interviewed state and local highway agency officials in 12 states to learn about the procedures their agencies used to establish work zone speed limits and the perceived effectiveness of various speed limit reduction policies. In addition, the research included interviews and surveys to determine the attitudes of motorists, construction contractors, and construction liability insurance carriers concerning how work zone speed limits should be set. The results were considered in planning field data collection on vehicle speeds, traffic accidents, and traffic conflicts in work zones.

A candidate procedure for appropriate work zone speed limits was formulated early in the research and revised, as appropriate, throughout the remainder of the project. This procedure was based on an assessment of the hazards present in each individual work zone. It was tested and revised using vehicle speed and traffic accident data collected for actual work zone sites. In the process, GME compiled a 7-state, 68-site work zone research data bank that included 27 speed study sites and 66 accident-data collection sites.

The operational data—including vehicle speeds, but traffic volumes, and traffic conflicts—were collected at selected work zone sites where activities lasted 3 days or more. Speed data were generally collected during daytime off-peak hours, but at some sites, they were collected during daytime peak or nighttime periods or both.

The accident data included records of accidents that occurred both before and during the work activities at stationary construction zones. A minimum 1-month work period was established for accident study sites. The work at most sites lasted considerably longer.

The accident and speed data were analyzed to determine the effects of specific levels of speed limit reduction on sites with a variety of roadway, area, and work types. Particular care was taken to determine the work zone speed limit policies that (1) minimized the increase in speed variance from upstream of the work zone to the increase in speed variance within the work zone and (2) minimized the increase in the traffic accident rate from the period before construction to the period during construction.

FINDINGS

This section summarizes the findings of the research. It includes a description of the findings of the literature review, which addressed speed zoning and speed control in general, and work zone speed zoning and control, in particular, a summary of state practices for establishing work zone speed limits, a summary of the field and accident data collection activities undertaken in the research; the results of the speed and accident studies; and the results of the surveys of motorists, construction contractors, and insurance carriers conducted during the research. A detailed explanation of these findings and the methods by which they were obtained is found in the appendixes of the final report. The subsequent Conclusions section addresses the interpretation of these findings, including a recommended procedure for determining work zone speed limits.

Literature Review Findings

The following discussion summarizes the findings of the literature review conducted during the research. The studies described here are presented in greater detail in Appendix A, which is not published herein.

Speed Zoning Overview

The establishment of speed zones is identified in the 1982 Federal Highway Administration (FHWA) "Synthesis of Safety Research Related to Traffic Control and Roadway Elements" as an important tool in promoting the safe and efficient operation of the highway system (*2*). Speed zones are established to encourage drivers to adopt safe travel speeds, to reduce the risk of accidents because of differences in vehicle speeds, and to allow the arrest of speed limit violators. Reasons for the establishment of speed zones can include urban development; small towns; poor horizontal or vertical geometrics; sight distance restrictions; intersections and driveways; congestion; adverse vehicle mix; pedestrian activity; and high accident rate. Speed zones established for these reasons are usually posted with regulatory speed limit signs. Speed zones may apply to specific areas, such as areas within city limits, without the need for speed limit signs.

The *Uniform Vehicle Code* (*3*) serves as a model for state traffic laws, but speed limit laws vary from state to state. Both absolute maximum and prima facie maximum speed limits are used in the United States. In addition to the national maximum speed limit, which has been adopted by every state, maximum speed limits have been adopted by individual state and local agencies for school zones, for specific vehicle classes (such as trucks), for specific times of day or lighting conditions (such as nighttime conditions), and for specific classes of highways (such as multilane, divided highways).

Advisory speed limits are posted for special situations such as sharp curves, grades, and intersections. Although advisory speed limits have been used in work zones, highway agencies are using regulatory speed limits more frequently in work zones, as described later in this section.

Virtually every traffic engineering reference work that addresses the principles of speed zoning or the installation of traffic control devices specifies the 85th percentile speed as the primary indicator of prevailing speeds to consider in establishing speed zones. Few of the standard traffic engineering references, including the *Transportation and Traffic Engineering Handbook* (*4*) and the *MUTCD* (*1*), however, offer any formal rationale for the use of the 85th percentile speed rather than some other measure of prevailing speed. Rowan and Keese (*5*) assert that the 85th percentile speed closely approximates a break point in most speed distribution curves above which speed ranges are associated with rapidly decreasing percentages of vehicles. Studies by Solomon (*6*) and Cirillo (*7*) indicate that accident involvement rates are lowest for vehicles traveling at approximately 8 to 10 mph above the average speed of traffic. This corresponds roughly to the 85th percentile speed of traffic.

Speed zoning criteria include other speed parameters and environmental factors; often, however, objective methods for assessing such criteria do not exist or are not used widely. For example, the pace—the 10-mph range containing the largest proportion of vehicles—is included in many speed zoning criteria, including the *MUTCD*, but an objective method for considering the pace speed range is seldom provided. One instance of an objective method for considering the pace, together with the 85th percentile speed, to establish maximum speed limits is provided by an Institute of Transportation Engineers (ITE) "Informational Report on Speed Zoning" (*8*) published in 1961.

The *MUTCD* incorporates other factors to be considered in establishing regulatory maximum speed limits, including road surface characteristics, shoulder condition, grade, alignment, sight distance, roadside development and culture, roadside friction, safe speeds for curves and other hazardous locations, parking practices, pedestrian activity, and reported accident experience; however, no guidelines for considering these factors are provided. Traffic engineers disagree on the extent to which such factors should be included. Some engineers stress the importance these factors have to safety, while others point out that these factors are reflected in prevailing speeds, whatever speed limits are applied. Perhaps all could agree on guidelines that stress the importance of considering these factors when their presence is not apparent to the driver.

Studies of isolated changes in speed limits have often found limits ineffective in reducing vehicle speeds (*9, 10, 11, 12, 13*). Some speed limit reductions have actually been counterproductive, resulting in increases in speeds (*14*). Other studies have confirmed that drivers respond to changing roadway conditions more than to posted speed limits (*15, 16*). Such findings (1) reinforce the principle that speed limits should be strongly influenced by prevailing speeds and (2) point to the need to keep speed limits reasonable, because arbitrarily low speed limits may produce noncompliance and disrespect for speed limits and for traffic control devices in general. Even though many drivers supported the 55-mph speed limit, research shows they continued to violate it (*17*).

While isolated changes in speed limits may not always be effective, research results indicate that the more dramatic changes in speed control can reduce speeds. For example, some European experience showed a substantial speed reduction when speed limits were imposed for the first time (*18, 19*). Research in another European country, however, found the introduction of a speed limit had no significant effect on traffic speeds or accidents (*20*). The researchers' experience with the national maximum 55-mph speed limit in the United States shows that, while it may not produce compliance, the imposition of the speed limit has reduced travel speeds.

A 1985 study by Parker (*21*) documented the results of an AASHTO survey on speed zoning practices. The engineering factors most frequently considered by U. S. and foreign highway agencies in setting maximum speed limits included 85th percentile speed, 10-mph pace, accident experience, and the type and amount of roadside development.

Recent FHWA research on speed zoning has confirmed many of the basic principles of speed zoning discussed previously (*22*). An analysis of travel speed and speed limit compliance concluded the following:

- Mean traffic speeds exceeded the posted speed limit by 1 to 8 mph.
- 85th percentile speeds ranged from 6 to 14 mph over the posted speed limit or 4 to 7 mph over the mean speed.
- Passenger cars travel 1 to 5 mph faster than trucks for all levels of speed limits.
- Most free-flow drivers (70.2 percent) did not comply with posted speed limits.
- Overall, 40.8 percent of drivers exceeded the posted speed limit by more than 5 mph, 16.8 percent exceeded the speed limit by more than

10 mph, and 5.4 percent exceeded the speed limit by more than 15 mph.

- In general, 85 percent compliance was achieved at speeds of 10 mph over the posted speed limit.
- Noncompliance was higher for passenger cars than for trucks at all speed limit levels.
- Excessive speeding (more than 10 mph over the posted speed limit) is more prevalent at night than during the day.

Research showed that the least amount of compliance with speed limits is on low-speed roads. On many roads, the posted speed limit has been set 8 or 12 mph below the 85th percentile speed, typically at a speed level that corresponds to about the 30th percentile speed of traffic (*23*).

Relationship of Speed and Speed Variance to Traffic Accidents

Solomon's (*6*), reported in 1964, is the most familiar study of the relationship between traffic accident involvement rate and deviation from average speed on two- and four-lane rural highways. Accident involvement rates were highest for vehicles at very low speeds, lowest at the average speed, and greater at very high speeds. Cirillo (*7*) established a similar relationship for freeways. Recent FHWA research by Tignor and Warren (*23*) studied single-vehicle and multiple-vehicle accidents and found a similar pattern to that found by Solomon and Cirillo with lowest accident involvement rates relatively close to the median speed of traffic. Another recent FHWA study by Harkey et al. (*22*) found a similar relationship that showed the speed at which accident risk was minimized occurred at the 90th percentile of the travel speeds observed, which was about 7 mph above the mean speed. Joscelyn et al. (*24*) found similar results to the other studies for higher speeds but did not find higher accident rates for lower speeds.

The relationships found by Solomon (*6*), Cirillo (*7*), Tignor and Warren (*23*), and Harkey et al. (*22*) show that accident rates increase with deviation from the average speed of traffic. This relationship between accident rate and deviation from mean speed implies that the speed variance is an important parameter because the percentage of vehicles traveling at speeds substantially greater than or less than the average speed increases with the speed variance.

The previously cited research on the relationship of speed variance and accident involvement rate shows that drivers who choose to travel faster than the average speed incur additional risk of an accident and increased accident severity for each increment of increased speed. Research by Jondrow, Bowes, and Levy (*25*) suggested that the speeds drivers choose represent their personal evaluation of the risk of a fatal accident and the relative values of travel time, fuel consumption, and loss of life. However, the risk that a driver incurs by choosing a particular travel speed includes a risk to other road users as well as the driver's personal or private risk. When the risk of others is considered, a social optimum speed, lower than the private optimum, can be determined. The social optimum speed could be thought of as a speed limit that would best represent the interests of all road users.

In a recent study, Garber and Gadirau (*26*) performed regression analysis of the relationship of accident rate to average speed and speed variance. They determined that speed variance will be minimum if the posted speed limit is between 6 and 12 mph lower than the design speed of the highway. Outside this 6- to 12-mph range, speed variance increases with increasing difference between the design speed and the posted speed limit. Garber and Gadirau (*26*) recommended that, in order to reduce speed-related accidents, speed limits should be posted 5 to 10 mph below the design speed for highways with design speeds of 50, 60, and 70 mph.

Using data from various countries and making several simplifying assumptions, Feldwick (*18*) found that the accident rate was related to rural speed limits. Roads with 45-mph speed limits had the lowest accident rates and roads with 80-mph speed limits had the highest accident rates.

The maximum speed limit in the United States was lowered to 55 mph in 1974 as a fuel-saving measure. The speed limits on most roads affected by the change were previously posted at 65 and 70 mph. Average speeds were reduced about 5 percent but varied according to road type and relative level of the speed limit (*19, 27*). Speed data collected in 1979 showed that compliance with the 55-mph speed limit was poor (*27*). From 30 to 60 percent of motorists were exceeding the 55-mph speed limit on a statewide basis and up to 80 percent were violating the speed limit on rural freeways.

Beginning in 1987, state highway agencies were allowed to increase the posted speed limit from 55 to 65 mph on rural freeways. A recent AASHTO survey showed little difference in average speeds between states that raised the speed limit on rural freeways and those that did not (*28*).

Studies of the introduction of the 55-mph speed limit have produced mixed results. Some studies have reported that the fatality rate decreased, but the injury rate did not (*20, 27*). Other studies have shown that highways most affected by the lower speed limit had the greatest reduction in fatality rates (*29, 30, 31, 32, 33, 34*). However, 8 of the 17 states examined by Heckard et al. (*29*) had increases or no significant change in fatality rates in 1974 in comparison to past trends.

Advisory Speed Limits

Advisory speed limits are often used to aid drivers in selecting safe speeds for potentially hazardous locations such as curves, road work sites, intersections, and road sections with lower design speeds.

Lyles (*35*) found that 35-mph advisory and regulatory speed signs had little effect on speed compared to the standard curve sign. Drivers reached their minimum speed at approximately the same point in the curve regardless of the signing used.

Ritchie (*36*) found that drivers exceeded advisory speed limits of 15 to 35 mph but did not exceed 45- and 50-mph advisory speed limits.

Bezkorovainy (*37*) found that drivers were not influenced by raising or lowering advisory speed limits but were influenced by the sharpness of the curve.

Graham et al. (*38*) in a 1977 FHWA study found that 40- and 45-mph advisory and regulatory speed limits in freeway work zones had no significant effect on speed but did increase traffic conflicts. Work zones with advisory and regulatory speed limit signing had higher accident increases during construction compared to those without speed reductions.

Hanscom (*39*) observed average speed reductions of about 7 mph at locations where a changeable-message "SLOW TO 45 MPH" speed advisory was used at freeway lane closures; however, average speeds never dropped below the 45-mph advisory speed.

Webb (*40*) observed speed reductions of 2 to 6 mph where a changeable-message sign displaying a 50-mph advisory speed limit was used. Traffic speed averaged 66 to 70 mph without the advisory speed limit.

Drivers who use a highway repeatedly quickly learn the speed that curvature and road conditions will allow and advisory speeds can be expected to have little effect on them.

School Zone Speed Limits

Speed limits are frequently established for school zones in response to the public perception that lower speed limits are a major factor in school zone safety. Although the public considers reduced speed limits "safe," previous studies have found poor driver compliance with school zone speed limits (*41, 42, 43, 44, 45*) and no relationship between pedestrian accidents and school zone speed limits (*41, 45, 46*). A recent Nebraska study by McCoy (*47*) found higher speeds in school zones with 15- and 20-mph speed limits than in school zones with 25-mph speed limits.

The use of flashing beacons to supplement school zone speed limits has had mixed results. Several studies reported that flashing beacons in conjunction with a speed limit sign reduced the speed of traffic by less than 4 mph, although speed reductions up to 10 mph have been reported at some sites (*43, 44, 45, 48*). Other studies, however, reported that vehicle speeds in school zones increased when the flashers were operating (*49, 50, 51*).

In summary, the available data show that school zone speed limits are ineffective in reducing vehicle speeds by more than 5 mph. Extremely low speed limits (15 and 20 mph) can be counterproductive and increase vehicle speeds above the levels found for higher school zone speed limits. In general, drivers do not feel constrained to obey speed limits that they consider unreasonable. Flashing beacons may be effective as a supplement to school zone speed limits, but the results are inconclusive.

Work Zone Speed Limits

For many years, most speed limits used in work zones were advisory speed limits. In recent years, however, many agencies have begun to use regulatory speed limits in work zones. Highway agency practices for work zone speed limits vary widely. These practices are reviewed in the following sections and in Appendix B, which is not published herein. The following discussion focuses on the results of research concerning work zone speed limits and their effects on vehicle speeds and on traffic accidents.

Effects on Vehicle Speeds

Most highway agencies that use regulatory speed limits in work zones believe that such limits will reduce vehicle speeds and prevent accidents. Published research reports and unpublished data indicate that regulatory speed limits are not very effective in reducing vehicle speeds in work zones (*38, 52, 53*).

A Minnesota work zone study by Jackels and Brannon (*54*) found that a regulatory 40-mph speed limit sign, on a normally 65-mph speed limit rural freeway, reduced the 85th percentile speed from 71 to 58 mph.

A recent study in Illinois by Benekohal (*55*) determined the speeds of free-flowing vehicles at several different locations in a rural freeway work zone. This work zone, on a freeway with a 65-mph speed limit for passenger cars and a 55-mph speed limit for heavy trucks, had 45-mph advisory speed limit signs in the advance warning area of the work zone and 45-mph regulatory speed limit signs in the work area. Passenger cars reduced their speed from 62.6 mph at the beginning of the taper to 49.3 mph at a work area where workers were present at a bridge repair site (4,400 ft downstream). Trucks reduced their speeds from 57.0 to 45.5 mph between the same locations. The standard deviation of speed for passenger cars was highest at the actual work area (9.28 mph), while trucks had their lowest standard deviation of speed at the work area (5.13 mph). These results showed that drivers do reduce speeds in work zones, especially when workers are present.

While the Benekohal study discussed previously did show a substantial reduction in vehicle speeds at one work zone site, this reduction in speed may have been partially because of the presence of workers as well as the posting of a regulatory speed limit. Most other studies of work zone speed limits have shown smaller effects (or no effect) of work zone speed limits on vehicle speeds. Research in Texas (*56, 57*) resulted in recommendations of speed limit reductions in work zones ranging from 5 to 20 mph, depending on the type of highway. In an FHWA report, Parker (*21*) suggested that work zone speed limits should be no less than 25 mph and that the maximum speed limit reduction should be 15 mph below the normal speed of traffic.

Researchers that found reductions in work zone speed limits to be ineffective in reducing speeds, generally evaluated the effectiveness of other methods of reducing speeds.

A 1977 FHWA study by Graham et al. (*38*) found that the presence of a police vehicle using radar reduced mean traffic speeds by 2.5 to 4.9 mph, depending on the location within the work zone.

A 1985 Texas study by Richards et al. (*56*) found that flagging (19 percent speed reduction), law enforcement (18 percent speed reduction), changeable-message signs (7 percent speed reduction), and lane width reduction (7 percent speed reduction) were the most effective speed reduction methods for use in work zones.

The Minnesota study (*54*) discussed previously found that the presence of a police vehicle in the work zone reduced the 85th percentile speed by 13 mph (from 58 to 45 mph) and that a radar-activated information sign reduced the 85th percentile speed by 5 mph (from 58 to 53 mph). When the police vehicle left the work zone to pursue a speeder, the 85th percentile speed increased 22 mph (from 45 to 67 mph).

A study in Missouri (*58*) that evaluated radar-controlled speed matrix signs concluded that such signs did produce modest speed reductions, but the presence of law enforcement officers in the work zone was more effective than any type of sign currently available.

A 1989 FHWA study reported several applications of rumble strips in work zones (*59*). A Texas evaluation found rumble strips ineffective in reducing vehicle speeds (*60*). Pigman and Agent (*61*) found that rumble strips reduced vehicle speeds. A rumble strip vendor found that its rumble strips reduced speeds by 8 mph compared to standard warning signs and by 4.5 mph compared to standard construction warning signs in conjunction with a 35-mph regulatory speed limit (*62*). A 1987 Ohio study found that rumble strips reduced speeds 7 mph on the approach to a median crossover (*63*).

Speed reductions of 0 to 3 mph were produced by flaggers directing traffic to proceed through the work zone on a rural Texas two-lane, two-way highway where the flaggers were used to alternate one-way traffic through the work zone (*64*).

Effects on Safety

Only limited evaluations have been conducted of the effects of work zone speed limits on safety. The 1977 FHWA study of 79 construction zones by Graham et al. (*38*) found that urban projects showed a 14 percent increase in accident rate without speed limit reductions and a 60 percent increase in accident rate with speed limit reductions. Rural projects showed a 2.6 percent increase in accident rate without speed limit reductions and a 16.4 percent increase in accident rate with speed limit reductions.

One method of speed control discussed previously is the use of narrower lanes in work zones. An evaluation of a project where 9-ft lanes were used found that the total accident rate increased from 1.68 accidents per million vehicle-miles to 2.63 accidents per million vehicle-miles (*65*). Injury-accident rates increased as well. When 10- and 11-ft lanes were used, the total accident rate was closer to the preconstruction level and the injury-accident rate was below the preconstruction level.

Rouphail et al. (*66*) studied correlations between traffic control device layouts and speed variance at approach, transition, and lane closure areas. The greatest speed reductions were observed at the transition area (lane closure taper) because of congestion created by lane-changing maneuvers. At single-lane closures, speed reductions between the approach and transition areas were 5.45 and 7.19 mph below low- and high-volume conditions, respectively. Where two lanes were closed, speed reductions between the approach and lane closure areas were 9.64 and 14.58 mph, respectively. Under light volume conditions, speed recovery between the transition and lane closure areas was negligible. Under high-volume conditions, mean speeds increased by 1.5 mph for single-lane closures and by 10.8 mph for two-lane closures.

A speed analysis by Rouphail et al. (*66*) found that large speed variations were influenced by inconsistencies in traffic control devices. Sites with short taper lengths, missing arrow panels, and missing signs or that were of short duration had higher speed variations than other sites. This finding supports the importance of adhering to standards.

Highway Agency Work Zone Speed Limit Policies and Guidelines

The work zone speed limit policies and guidelines of each state highway agency were investigated to determine what methods are currently being used to establish work zone speed limits. This information was obtained from recent surveys conducted by the Florida Department of Transportation (DOT) and the Mississippi State Highway Department. A questionnaire was mailed to each of the 50 state highway agencies and to the District of Columbia and Puerto Rico; agencies were asked to confirm their work zone speed limit policies, as presented in the reports of the Florida and Mississippi surveys. Of the 52 highway agencies contacted, 45 responded.

The survey results indicated that three general policies are used by state highway agencies for establishing work zone speed limits: (1) policies based on avoiding the need for speed limit reductions whenever possible; (2) policies based on blanket speed limit reductions at all work zone sites; and (3) policies under which the need for a work zone speed limit reduction is established on the basis of specific factors.

Table 1 identifies which states use which policy categories. Eighteen states avoid reducing the work zone speed limit whenever possible. Five states have blanket work zone speed limit reduction; that is, they reduce the work zone speed limit in all or nearly all cases. (One of these five states uses a blanket speed limit reduction only in maintenance work zones; speed limits in construction zones are determined case by case.) Twenty-nine states followed an established procedure or an established set of factors in deciding whether to use a reduced work zone speed limit. The geographic distribution of the policies throughout the United States is illustrated in Figure 1.

The following sections discuss each of the work zone speed limit policy categories.

TABLE 1 Types of work zone speed limit policies

States that avoid reducing work zone speed limits whenever possible	States with "blanket" reduced work zone speed limits	States that reduce work zone speed limits based on an identified procedure or set of factors	
Alabama	Georgia	Arizona	Oklahoma
Alaska	Louisiana	Colorado	Pennsylvania
Arkansas	Michigan	Delaware	Rhode Island
California	Montana	Hawaii	South Carolina
Connecticut	Vermont	Idaho	Tennessee
District of Columbia		Illinois	Utah
Florida		Indiana	Texas
Iowa		Kansas	Washington
Maine		Kentucky	West Virginia
Maryland		Minnesota	Wisconsin
Massachusetts		Missouri	Wyoming
Mississippi		Nebraska	
Nevada		New Hampshire	
North Carolina		New Jersey	
Oregon		New Mexico	
Puerto Rico		New York	
South Dakota		North Dakota	
Virginia		Ohio	

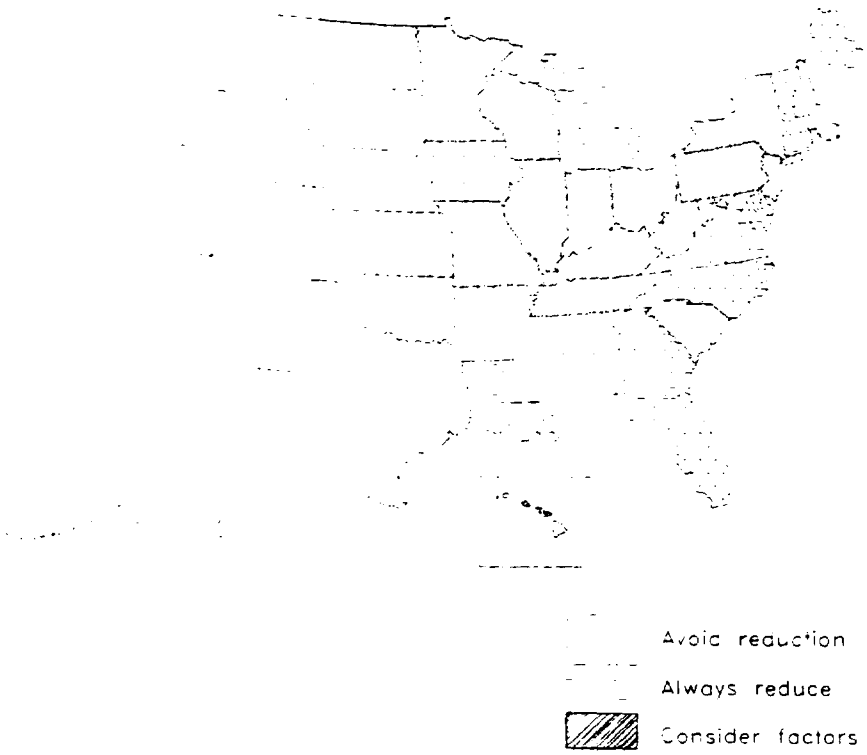


Figure 1. Work zone speed limit reduction policies.

Policies Based on Avoiding the Need for Speed Limit Reductions

Eighteen states have policies intended to avoid work zone speed limit reductions whenever possible. These states identified in Table 1 and in Figure 1, try to plan the work zone traffic control strategy and the geometric design of the work zone to operate safely at the existing posted speed limit. In situations where this is not possible, many of these agencies use a set of factors to determine if there is a need for a speed limit reduction. Of the 18 states, 13 listed specific factors that they consider in assessing the need for a speed limit reduction.

Of the 18 states, 15 use regulatory speed limit signing where they find it necessary to reduce the speed limit. The other three states (Connecticut, Massachusetts, and Mississippi) use advisory speed limits as the primary speed-reduction technique.

Both the California Department of Transportation (Caltrans) and the Florida DOT—in order to avoid reducing work zone speed limits whenever possible—require an engineering study if a regulatory work zone speed limit is to be implemented.

Caltrans uses reduced speed limits only in areas where the traveling public is affected by construction operations. Speed limit signs are moved as construction progresses. Caltrans believes that putting speed limits in areas where no construction is taking place encourages disrespect for the speed zone and reduces the effectiveness of the speed limit at locations where it is really needed.

The Caltrans policy for establishing work zone speed limits is based on its policy for establishing speed zones of all types. Thus, Caltrans establishes speed limits at or near the 85th percentile speed. The policy states that speed limits higher than the 85th percentile do not facilitate the orderly movement of traffic. Only when roadside development results in traffic conflicts or when unusual conditions are present and not readily apparent to drivers are speed limits below the 85th percentile warranted. Physical conditions—such as width, curvature, grade, and surface conditions or any other conditions readily apparent to the driver—in absence of other factors, would not require special speed zoning.

In contrast, the Florida DOT does not use the 85th percentile speed for work zone speed limits. Its policy states that changes to the existing speed limit should be made on actual or anticipated geometric, traffic volume, or work zone conditions but not on prevailing speeds.

The Florida DOT uses both regulatory and advisory speed limits and its policy is that the speed limit should not be reduced more than 20 mph below the normal posted speed limit. Advisory speed limits are enforceable in Florida as "careless driving." The Florida DOT requires that permanent speed limit signs are to be removed or covered when a regulatory work zone speed limit is in effect. The work zone speed limit signs must be removed as soon as the conditions requiring the reduced speed no longer exist. Once the regulatory work zone speed limit signs are removed, the preconstruction speed limit prior to construction automatically goes back into effect, unless the district traffic operations engineer issues a regulation to change the speed zone.

The objective of the Florida DOT is to move traffic through work zones in a manner comparable to normal highway conditions. The Florida DOT work zone speed limit procedure was used as the basis for the procedure developed in this research. The Florida DOT has developed guidelines for establishing work zone speed limits under the following seven conditions:

1. Activities that are more than 15 ft from the edge of pavement,
2. Activities that encroach on the area closer than 15 ft but not closer than 2 ft to the edge of pavement,
3. Activities that encroach on the area from the edge of the pavement to 2 ft from the edge of pavement,
4. Activities that encroach on the area between the centerline and the edge of pavement (lane closures),
5. Activities that require an intermittent or moving operation on the shoulder,
6. Activities that require construction of a temporary detour, and
7. Activities that encroach on the area beyond either the centerline of a roadway or a lane line of a multilane highway.

For each work zone condition, the Florida DOT guidelines present typical applications, duration of work, reduction of regulatory speeds, and the suggested amount of reduction.

The Iowa DOT is an example of a state highway agency that tries to avoid reducing work zone speed limits wherever possible. The Iowa DOT tries to avoid work zone speed limit reductions on rural freeways, with the exception of work zones where traffic in one direction is detoured onto another roadway, resulting in two-lane, two-way traffic operations. For freeway work zones with two-lane, two-way traffic operations, the work zone speed limit is reduced from 65 to 55 mph.

Policies Based on Blanket Speed Limit Reductions

Five states have blanket work zone speed reduction policies, that is, the speed limit is always or nearly always reduced in work zones. These states are identified in Table 1 and Figure 1.

Michigan uses a 45-mph regulatory speed limit in work zones. Georgia, Louisiana, and Vermont use 40-mph speed limits. Montana uses a 35-mph speed limit.

The 45-mph work zone speed limit in Michigan applies primarily to work zones with lane closures. A speed limit reduction is not mandated where work is on or outside of the shoulder or in work zones without lane closures—even those with narrow lanes or curvilinear path. A statute to be introduced in the Michigan legislature will allow speed limits other than 45 mph, thus providing more flexibility to the agency in setting work zone speed limits.

Louisiana normally uses a 40-mph regulatory speed limit in work zones, however, Louisiana reduces the speed limit to 20 mph where traffic is close to workers. No exceptions to the policy were noted.

The Vermont blanket speed limit reduction to 40 mph applies to work zones on freeways and other limited access facilities. No speed reduction is recommended on other highway types.

Georgia uses a regulatory work zone speed limit of 40 mph. This blanket 40-mph speed limit generally is applicable only to maintenance work zones that involve work in the traveled way. Typically such projects only use the reduced speed limit during the day when work activities are in progress. The blanket 40-mph speed limit does not apply to speed limits in construction zones. Speed limits in construction zones are established on a case-by-case basis.

Montana typically posts its reduced 35-mph speed limit throughout the length of the project—not just in the work area. This policy is in contrast to those of California and Florida, which discourage reduced speed limits in inappropriate portions of the work zone. Montana believes that signing the entire project with a reduced speed limit reduces its potential liability for work zone accidents.

Policies with Speed Limit Reductions Based on Specific Factors

Twenty-nine states reduce speed limits in some work zones but not in others, on the basis of specific sets of factors. These states are identified in Table 1 and Figure 1. Eighteen of the states use regulatory speed limits when the work zone speed limit is reduced. Ten states use both regulatory and advisory work zone speed limits. Most of these 10 states have advisory speed limits that are enforceable. Pennsylvania is an exception where advisory speed limits are used in some cases although only regulatory speed limits are enforceable. West Virginia is the only state where work zone speed limits cannot be reduced with regulatory signs. All work zone speed limits in West Virginia are implemented with advisory signs.

Eight state agencies stated that they typically used 10-mph speed limit reductions in work zones. Four agencies stated that they typically used work zone speed limit reductions of 10 to 20 mph.

As in California and Florida, Texas policy states that regulatory speed limits in work zones should be posted only within the section of roadway where speed reduction is necessary for the safe operation of traffic and protection of construction personnel.

Two states require the speed limit to be documented in the project file or traffic control plan. Wyoming has a set of typical traffic control plans with reduced regulatory speed limit signs on them.

Illinois, Missouri, and Tennessee use reduced speed limit signs with flashers and a supplementary sign that indicates that the reduced speed limit is applicable "WHEN WORKERS ARE PRESENT." For example, Missouri uses flashing lights on their regulatory speed limit signs in work zones on divided highways to indicate that the speed limit is reduced to 45 mph. When workers are not present, the speed limit on such highways is typically 55 mph. One potential problem with this approach is that the flashing lights are occasionally left on by mistake at times when no work is being done and no workers are present in the work zone. At one location, the research team observed the flashing lights on speed limit signs in operation at night when no work was underway.

Some states require an engineering and traffic investigation to justify a speed limit reduction; others allow reductions without a formal study. Some states specify the work zone speed limit in the traffic control plan design phase, while others determine the speed limit at the job site. For example, the New York State DOT has two methods for establishing regulatory work zone speed limits for construction projects. One method used is to file an official department order with the secretary of state; this is a cumbersome procedure because work zone speed limits may change often. The other method is for the engineer-in-charge at the work site to set the speed limit under the restricted highway provision of state law; this does not require a separately filed order. There is no written policy for determining work zone speed limits under this procedure.

Table 2 summarizes the factors used by state highway agencies in establishing work zone speed limits. A total of 41 different factors were identified by 37 agencies. The frequency with which each factor was mentioned is an indication of its perceived importance by highway agencies. Lane width, alignment, and type of work zone were mentioned most often. Some responses mentioned lane widths of 10 or 11 ft as being critical in establishing work zone speed limits.

The consideration of alignment in determining work zone speed limits generally refers to the presence of horizontal and vertical curvature built or designed to standards less than that of the adjacent roadway. Some agencies have established a direct link between the design speed of the alignment and the posted work zone speed limit.

Type of work zone refers to the type of traffic control procedure or the location of the work activity. Work in the traveled way generally is considered more critical than work on the shoulder, and work on the shoulder is considered more critical than work outside of the shoulder.

Other common factors considered by highway agencies in setting work zone speed limits include sight distance, prevailing speeds, presence of workers, accident experience, presence of barriers, and roadway type.

Methods for Increasing Speed Limit Compliance

State highway agencies have used several methods to increase compliance with work zone speed limits. Although these methods were not a major focus of the research reported here, they may be essential for effective speed control at sites where reduced speed limits—reflecting engineering factors rather than prevailing speed—are employed. Table 3 lists work zone speed control methods. Flagging, law enforcement, changeable-message sign, and lane width reduction were found effective by the Texas Transportation Institute (TTI).

Accident and Traffic Operational Field Data Collection

The effectiveness of work zone speed limits was evaluated in this study through collection of traffic accident data and traffic operational field data at 68 work zones. These work zones were located in seven states that use various practices for determining work zone speed limits. Three of the states avoid reducing work zones speed limits whenever possible (i.e., California, Florida, and Iowa); two states use blanket speed limit reductions (i.e., Georgia for maintenance work zones and Montana for all work zones that involve work in the traveled way); and two states consider engineering factors in determining the need for speed limit reduction in work zones (i.e., Missouri and New York).

The sites were distributed among states as follows:

California	11 sites
Florida	7 sites
Georgia	9 sites
Iowa	14 sites
Missouri	4 sites
Montana	11 sites
New York	12 sites
	68 sites

The following roadway types, arranged in decreasing priority, were selected for the study:

TABLE 2 Factors used for establishing work zone speed limits

Factor	Frequency
Lane width	16
Alignment	14
Type of work zone	12
Sight distance	10
Prevailing speeds	9
Workers present	8
Accident experience	7
Presence of barrier	7
Roadway type	7
Driver expectancy/unexpected conditions	5
Traffic volume	5
Presence of pavement edge dropoff	4
Congestion	3
Construction equipment movements	3
Design speed	3
Engineering judgment	3
Road surface conditions	3
Duration of work	2
Existing speed limit	2
Lack of shoulder	2
Pedestrian activity	2
Presence of equipment	2
Approach speed	1
Distance from traffic to workers	1
Distance to barrier	1
Distance to work area	1
Erratic maneuvers	1
Lack of compliance with flagger	1
Length classification of roadway	1
Night classification of roadway	1
Night construction	1
Number of lanes	1
Other safety-related factors	1
Physical conditions	1
Preconstruction speed limit	1
Presence of flagger	1
Roadside development/driveway access	1
Roadside conditions	1
Temporary signalization	1
Undesirable working conditions	1
Vehicle mix (trucks)	1
Previous experience with similar work zones	1

TABLE 3 Speed control methods employed in work zones

Speed control methods
Flagging
Law enforcement
Changeable-message sign
Lane width reduction
Regulatory and advisory signing
Dynamic speed limit signing
Traffic-activated signing
Truck-mounted sign
Work zone deaths sign
Radar
Mock-up of a police car
Unused police car
Increased fines for infractions
Flashing lights on signs
High-visibility clothing
Iowa weave section
Rumble strips
Speed bumps and humps
Pacing
Pilot vehicle
Transverse striping
Colored or textured pavement
Traffic queue (congestion)
Highway advisory radio
Traffic signals

- Rural freeway or expressway,
- Urban freeway or expressway,
- Rural multilane or rural two-lane highway,
- Rural two-lane highway detour—free flow maintained, and
- Urban arterial.

These sites included work zones with speed limit reductions ranging from 0 to 30 mph.

Appendix C, which is not published herein, identifies the work zone sites studied; their speed limits; the type of area (e.g., urban or rural); the type of highway; and the location of the work relative to the traveled way. Table 4 summarizes the number of work zones studied for each combination of area type, highway type, and location of work.

Data collection and analysis activities in the study included the following:

- Traffic accident data were obtained and analyzed for 66 of the 68 work zones. The traffic accident studies included comparisons of accident rates before and during construction or maintenance at each work zone site.
- Traffic speed studies were performed in the field at 27 of the 68 study sites. Thirty-four speed studies were performed at these sites. The speed studies included 27 daytime off-peak, 3 daytime peak, and 4 nighttime studies, as well as special studies of changeable-message signs and radar effects. For all but four studies, vehicle speeds were determined by videotaping vehicles traversing a trap of known length (50 ft). Speeds at the remaining sites, where videotaping was not feasible, were measured with traffic radar. Each speed study involved the collection of speed data both upstream of and within each work zone.
- Traffic conflict and erratic maneuver counts were made during the speed study period at 14 work sites.

Figure 2 illustrates the typical locations for field data collection activities upstream of and within work zones. Speed data were collected at these locations by videotaping vehicles traversing a known distance. Speed studies were performed for both peak and off-peak conditions; in addition, speed studies were performed at night for selected sites. The following sections summarize the results of the analyses of these data.

Speed Data Analysis

This section summarizes the findings of the analysis of vehicle speeds performed with the field data. The analysis addressed the effect of work zones and work zone speed limits on mean speeds, speed limit compliance, 85th percentile speeds, and speed variance.

Analysis of Mean Speeds. An analysis was conducted to determine how effective work zone speed limits are in reducing the mean speed of traffic. Table 5 summarizes the results of the analysis of mean speeds upstream of and within highway work zones as a function of the magnitude of the speed limit reduction. This table reflects analysis of the daytime off-peak speed studies for 22 sites, which are referred to as the basic study sites.

The table shows that motorists do slow down in work zones, even at locations where there is no speed limit reduction. The mean speed of traffic in the work zone was less than the mean speed of traffic upstream of the work zone by a statistically significant amount for 19 of the 22 basic study sites. At sites where the speed limit was not reduced, the mean speed in the work zone for all vehicles was 5.1 mph less than the mean speed upstream of the work zone.

In work zones where the speed limit is reduced, the reduction in the mean speed of traffic in the work zone (relative to the mean speed of traffic upstream of the work zone) generally increases as the amount of the speed limit reduction increases. The size of the reduction in mean speed increased from 7.2 mph for a 10-mph speed limit reduction to 20.7 mph for a 30-mph speed limit reduction. However, the observed reductions in mean speed in the work zone were consistently less than the magnitude of the speed limit reduction. The mean speeds of motorists in work zones were reduced by 51 to 72 percent of the magnitude of the speed limit reduction and there is no evident relationship of this percentage to the magnitude of the speed limit reduction.

TABLE 4 Work zones studied by area type, highway type, and location of work

Location of Work	Rural				Urban				COMBINED
	Freeway	Multilane	Two-Lane	TOTAL	Freeway	Multilane	Two-Lane	TOTAL	
Traveled Way	20	0	9	29	7	1	0	8	**37**
Detour	10	0	0	10	1	1	0	2	**12**
Shoulder	2	0	3	5	5	0	1	6	**11**
Roadside	0	0	2	2	6	0	0	6	**8**
TOTAL	32	0	14	46	19	2	1	22	**68**

TABLE 5 Summary of reductions in mean speed between upstream and work zone locations

Speed Limit Reduction (mph)	Number of Sites	Reduction in mean speed (mph) between upstream and work zone location		
		All vehicles	Cars	Trucks
0	5	5.1	4.8	5.5
10	4	7.2	7.7	5.5
15	3	7.8	8.2	4.5
20	7	13.6	13.9	12.4
25	2	12.7	12.7	12.6
30	1	20.7	24.6	17.8

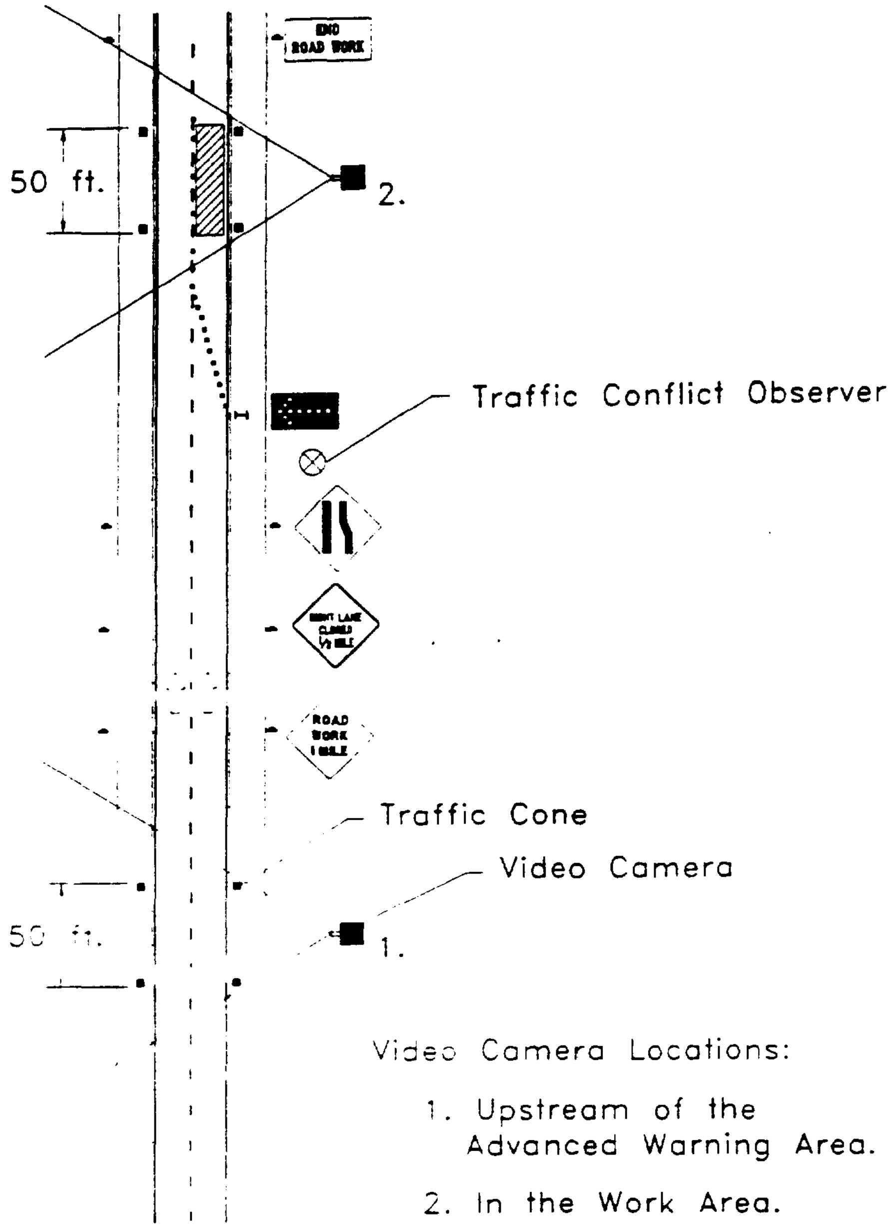


Figure 2. Data collection locations.

Work zones with a 10-mph speed limit reduction produced only slightly larger reductions in mean speed than the work zones with no reduction in speed limit (7.2 mph versus 5.1 mph). However, as will be shown later, work zones with a 10-mph speed limit reduction generally had smaller increases in speed variance than work zones with no speed limit reduction.

Work zones with a 15-mph speed limit reduction resulted in reduction in mean speed that was only marginally greater than for a 10-mph speed limit reduction (7.8 mph versus 7.2 mph).

Work zones with 20- and 25-mph speed limit reductions resulted in about the same reduction in mean speed (13.6 and 12.7 mph, respectively) and, at the one site with a 30-mph speed limit reduction, one of the largest reductions in mean speed (20.7 mph) was obtained.

Work zone speed limits less than the upstream speed limit generally resulted in slightly greater reduction in the speeds of passenger cars than trucks, although the differences are not large (usually less than 1 mph). At sites with no speed limit reduction, however, trucks actually slowed more than did passenger cars (5.5 mph versus 4.8 mph).

Analysis of Speed Limit Compliance. An analysis was conducted to determine the effect of work zone speed limits on speed limit compliance. It would be desirable to establish work zone speed limits in a manner that encourages compliance with speed limits. Table 6 shows the effect of work zone speed limits on the percentage of vehicles exceeding the speed limit upstream of and within work zones. The table shows the <u>decrease</u> in the percentage of vehicles exceeding the speed limit in the work zone in relation to the percentage of vehicles exceeding the speed limit upstream of the work zone.

At work zones with no speed limit reduction, the percentage of vehicles exceeding the speed limit is generally lower in the work zone than upstream of the work zone. The percentage of motorists traveling within the speed limit increased, on the average, by 21.7 percent from the upstream location to the work zone location. This finding follows very logically from the data in Table 5, which show that motorists travel about 5 mph slower in a work zone than they do upstream, even when the speed limit is not reduced.

For work zone sites with a 10-mph reduction in speed limit, it was found that speed limit compliance was, on the average, unchanged from upstream of the work zone to within the work zone. However, a review of the individual sites found that speed limit compliance increased substantially at two sites and decreased substantially at two other sites. This is an example of the high site-to-site variability that was found in the speed data.

For work zones with speed limit reductions of 15 mph or more, speed limit compliance was generally lower in the work zone than in the upstream area; in other words, speed limit noncompliance increases at higher speed limit reductions. This follows logically from the data in Table 5 which show that, on the average, motorists do not reduce their speeds by as much as the reduction in posted speed limit.

The same pattern found for all vehicles in Table 6 was also found for passenger cars. However, for trucks, speed limit compliance increased in work zones with no speed limit reductions but decreased in all work zones where the speed limit was reduced by any amount.

In summary, the level of speed limit compliance in work zones increased, compared to upstream sites, if the work zone speed limit is unchanged. Where the work zone speed limit is reduced by 10 mph, the level of compliance is the same, on the average, upstream of the work zone and within the work zone. Where the work zone speed limit is reduced by 15 mph or more, the level of speed limit compliance in the work zone is less than that upstream of the work zone.

Analysis of 85th Percentile Speeds. An analysis was conducted to determine how effective work zone speed limits are in reducing the 85th percentile speed of traffic. Table 7 summarizes the results of the analysis of 85th percentile speeds upstream of and within highway work zones as a function of the amount of the speed limit reduction.

The patterns observed in the 85th percentile speed data are very similar to the patterns reported previously for the mean speed data; the effect of work zone speed limit reduction on 85th percentile speed is generally about 2 to 3 mph less than the corresponding effect on mean speed. No formal statistical analysis of the 85th percentile speeds was

TABLE 6 **Summary of change in percent of vehicles exceeding the speed limit between upstream and work zone locations**

Speed Limit Reduction (mph)	Number of Sites	Change in percent of vehciles exceeding the speed limit between upstream and work zone location		
		All vehicles	Cars	Trucks
0	5	21.7	20.7	22.6
10	4	0.0	5.3	-19.4
15	3	-28.0	-26.7	-37.4
20	7	-3.1	-11.5	-10.8
25	2	-16.5	-11.5	-32.0
30	1	-33.0	-7.0	-70.0

NOTE: Positive changes indicate greater speed limit compliance in the work zone than upstream of the work zone
Negative changes indicate lower speed limit compliance in the work zone than upstream of the work zone

TABLE 7 **Summary of reductions in 85th percentile speed between upstream and work zone locations**

Speed Limit Reduction (mph)	Number of Sites	Reduction in 85th percentile speed (mph) between upstream and work zone location		
		All vehicles	Cars	Trucks
0	5	4.5	3.7	4.9
10	4	5.5	6.5	[illegible]
15	3	7.0	7.8	1.7
20	7	11.8	9.2	10.8
25	2	10.0	9.0	11.8
30	1	18.0	21.0	21.0

TABLE 8 Summary of speed variance results

Speed Limit Reduction (mph)	Number of Sites	Percent increase in speed variance between upstream and work zone location		
		All vehicles	Cars	Trucks
0	5	61.2	81.8	11.8
10	4	34.1	46.8	14.4
15	3	86.7	79.6	159.3
20	7	82.6	93.5	182.9
25	2	92.6	206.3	32.5
30	1	80.6	70.8	94.6

conducted, because the observed trends are so similar to the observed trends for mean speeds.

Analysis of Speed Variances. The analysis of speed variance data was very important to the research objectives. The literature shows that the speed variance is generally higher in the work zone than upstream of the work zone. The literature also indicates that speed variance is a potentially useful surrogate measure for safety. In interpreting the speed variance data, it should be kept in mind that the standard deviation of speeds, which may be more familiar to some readers, is the square root of the variance. In other words, if the speed variance is 29.9 mph^2, then the standard deviation of speed is the square root of 29.9, or 5.5 mph.

Table 8 summarizes the percent increase in speed variance between the upstream and work zone locations for the sites studied for each level of work zone speed limit reduction. The work zone speed variance was found to be significantly higher than the upstream speed variance at approximately half of the study sites. In most of the remaining cases, the speed variance in the work zone is higher than the upstream speed variance, but the difference was not large enough to be statistically significant. In none of the few cases in which the observed work zone speed variance was lower than the upstream speed variance was this difference statistically significant.

Table 8 has obvious implications for setting work zone speed limits in such a way as to minimize the increase in speed variance in the work zone. This percentage increase in speed variance appears to go through a minimum at a speed limit reduction of 10 mph. To summarize, it appears that, for work zones with speed limits that are not reduced, the speed variance in the work zone (for all vehicle types) is 61 percent higher than the upstream speed variance. For work zones with a 10-mph speed limit reduction, the increase in speed variance in the work zone is only 34 percent. Finally, for work zones with speed limit reductions of 15 mph or more, the increase in the work zone speed variance over the upstream speed variance ranges from 81 to 93 percent.

However, an important caveat in interpreting Table 8 is that none of the differences between the percent increases in speed variance that are shown in the table are statistically significant. Although disappointing, this finding reflects the diversity of conditions inherent in work zones. For example, the five work zones with no speed limit reduction, all of which happen to be located on freeways with 55-mph speed limits, had speed variance differences that ranged from a 19 percent upstream-to-work-zone reduction in speed variance to a 208 percent increase. Given motorist responses that are so highly variable, it is unlikely that statistically significant differences can be found.

Despite the lack of statistical significance, rational policies for setting work zone speed limits must be developed. The researchers consider it reasonable to use the speed variance results in Table 8 as a basis for policy if the accident analysis provides similar findings and if engineering judgement suggests that these findings are reasonable.

Accident Data Analysis

This section presents the findings of the analysis of traffic accidents performed in the research. The analysis addressed the effect of work zones and work zone speed limits on work zone accident rates. The literature indicates that traffic accident rates in work zones are generally higher than the traffic accident rates experienced at the same site during normal operations before the beginning of construction or maintenance. The accident analysis is based on the hypothesis that the most desirable policy for determining work zone speed limits is a policy that minimizes the increase in accident rate during the work period.

Table 9 summarizes the total length, exposure (million vehicle-miles of travel), number of accidents, and accident rates before and during construction for the 66 work zone sites included in the accident study. The table shows that the work zones in the study include 444.9 miles of roadway, or an average of 6.74 mi per site. The average length of site is relatively high because a number of the projects involved resurfacing extended sections of roadway.

The table shows that the accident database included over 3 billion vehicle-miles of travel in the study periods before construction and over 4 billion vehicle-miles of travel in the study periods during construction. The total exposure for the "during" periods is higher than for the "before" periods because some sites at which the construction extended for several years had a "before" period that was only a year or so in duration.

The database developed for the study consisted of 12,150 accidents, including 5,017 accidents in the "before construction" period and 7,133 accidents in the "during construction" period for the individual sites.

Table 9 shows that the total accident rate of the study sites was, on the average, 6.7 percent higher during construction than before construction, while the fatal and injury accident rate was, on the average, 6.9 percent higher during construction than before construction.

On the basis of preliminary analyses of the data, separate accident analyses were performed for groups of sites defined by the following factors:

- Area type (e.g., urban or rural),
- Highway type (e.g., freeway or two-lane), and
- Location of work (e.g., traveled way, detour, shoulder, or roadside).

Table 10 summarizes the percentage increase in accident rate (per million vehicle-miles) for each combination of these variables for which enough data were available for an analysis to be conducted. The results of these accident analyses are summarized below.

Analysis of Traveled Way and Detour Work Zones on Rural Freeways. The largest accident data set available for analysis consisted of 29 sites involving traveled way or detour work zones on rural freeways. Table 10 shows that, overall, these zones experienced an increase of 41.3 percent in total accident rate and of 30.7 percent in fatal and injury accident rate during the construction period.

Table 11 summarizes the mean percent increase in accident rate during the construction period as a function of speed limit reduction. The results presented in Table 11 are noteworthy because they show a characteristic pattern that is also present in the results of the speed variance analysis in Table 8. Specifically, the table shows that the minimum percent increase in accident rate during the construction period occurs for a 10-mph speed reduction. The differences between the mean percentage increase in accident rate for a 10-mph speed reduction and the other values shown in Table 11 are not statistically significant for total accident rate, but they are statistically significant for fatal and injury accident rate.

The findings presented in Table 11 imply that, at least for traveled way and detour work zones on rural freeways, a speed limit reduction of 10 mph will provide the minimum increase in accident rate.

Analysis of Traveled Way and Detour Work Zones on Urban Freeways. Table 10 shows that in traveled way and detour work zones on urban freeways, total accident rate increased by 34.2 percent and fatal and injury accident rate increased by 24.7 percent during the construction period. Table 12 summarizes the mean percent increase in accident rate during the construction period as a function of speed limit reduction.

The data in Table 12 imply that speed limit reductions up to 15 mph do not have an adverse effect on accident experience, but that accident rates increase substantially for a work zone speed limit reduction of 20 mph. However, the data for a 20-mph speed limit reduction are based on only one site and no conclusions can be drawn about the statistical significance of the difference in percent increase in accident rate between this site and the other sites. Despite this inability to test for statistical significance, the substantial increase in accident rate associated with the site that has a 20-mph speed limit reduction is consistent with the other results presented in this report.

Analysis of Shoulder and Roadside Work Zones on Rural Freeways. Only two of the study sites involved shoulder and roadside work on rural freeways. These data sites did not provide enough data to perform any meaningful analysis of speed limit practices.

Analysis of Shoulder and Roadside Work Zones on Urban Freeways. Table 13 compares the mean percent increase in accident rate for 10 sites with no speed reduction and one site with a 20-mph speed limit reduction. Because the 20-mph speed limit group includes only one site, no statistical conclusions can be drawn. However, the data imply that substantial increases in accident rate are associated with a 20-mph speed limit reduction. This observation is consistent with the results of the

TABLE 9 Summary of accident experience at study sites

	Before Period	During Period	Percent Increase
Total length of study sites (mi)	444.9	444.9	
Total exposure (MVMT)	3084.7	4112.0	
Total number of accidents in period	5017	7133	
Total number of fatal and injry accidents (see Note 1)	1743	2488	
Total accident rate (per MVMT)	1.63	1.73	**6.7**
Fatal and injury accident rate (per MVMT) (see Note 1)	0.57	0.61	**6.9**

Note 1: Excludes Site FL01 for which fatal and injury accident data were not available.

TABLE 10 Summary of percentage increase in accident rate by area type, highway type, and location of work

Area Type (Urban/ Rural)	Highway Type	Location of Work	Before Period					During Period					Percent Increase	
			Exposure (MVMT)	No. of Total Accs	Total Acc Rate	No. of F&I Accs	F&I Acc Rate	Exposure (MVMT)	No. of Total Accs	Total Acc Rate	No. of F&I Accs	F&I Acc Rate	Total Acc Rate	F&I Acc Rate
Rural	Freeway	Traveled Way/ Detour	792.29	661	0.83	209	0.26	1261.47	1487	1.18	435	0.34	41.3	30.7
Rural	Freeway	Shoulder/ Roadside	22.66	23	1.02	6	0.26	31.93	31	0.97	6	0.19	-4.3	-29.0
Urban	Freeway	Traveled Way/ Detour	746.60	836	1.12	347	0.46	940.05	1413	1.50	545	0.58	34.2	24.7
Urban	Freeway	Shoulder/ Roadside	1388.06	3049	2.20	1040	0.75	1707.15	3669	2.15	1313	0.77	-2.2	2.7
Rural	Two-lane	Traveled Way/ Detour	32.50	55	1.69	14	0.43	32.22	80	2.48	24	0.74	46.7	72.9
Rural	Two-lane	Shoulder/ Roadside	46.78	132	2.82	38	0.81	56.68	152	2.68	49	0.86	-5.0	6.4

TABLE 11 Percent increase in accident rate by speed limit reduction group for traveled way and detour work zones on rural freeways

Speed Limit Reduction (mph)	Number of Sites	Mean % increase in Total Accident Rate	Mean % increase in Fatal and Injury Accident Rate
0	5	59.5	98.6
10	9	42.3	4.1
15	4	54.4	147.9
20	6	99.8	112.5
25/30	3	(a)	(a)

NOTE: (a) insufficient data

TABLE 12 Percent increase in accident rate by speed limit reduction group for traveled way and detour work zones on urban freeways

Speed Limit Reduction (mph)	Number of Sites	Mean % increase in Total Accident Rate	Mean % increase in Fatal and Injury Accident Rate
0	5	-2.1	-8.7
10	1	8.3	-9.9
15	1	15.8	-17.1
20	1	76.1	51.1
25/30	—	—	—

TABLE 13 Percent increase in accident rate by speed limit reduction group for shoulder and roadside work zones on urban freeways

Speed Limit Reduction (mph)	Number of Sites	Mean % increase in Total Accident Rate	Mean % increase in Fatal and Injury Accident Rate
0	10	10.1	21.9
10	—	—	—
15	—	—	—
20	1	78.4	70.9
25/30	—	—	—

speed variance analysis and the rural freeway accident analysis.

Analysis of Traveled Way and Detour Work Zones on Rural Two-Lane Highways. Table 10 shows that in traveled way and detour work zones on rural two-lane highways, the total accident rate increased by 46.7 percent and fatal and injury accident rate increased by 72.9 percent during the construction period. Table 14 summarizes the mean percent increase in accident rate during the construction period as a function of speed limit reduction.

The sites on rural two-lane highways generally have so few accidents that no meaningful conclusions can be drawn. The data for total accident rate shown in Table 14 appear to confirm the finding that no speed limit reduction is better from a safety standpoint than a large speed limit reduction. The fatal and injury accident data are highly variable; most sites experienced only one or two fatal and injury accidents. None of the differences between the values shown in Table 14 are statistically significant.

Analysis of Shoulder and Roadside Work Zones for Rural Two-Lane Highways. Accident data are available for four shoulder and roadside work zones on rural two-lane highways. Only one of these four sites experienced a substantial number of accidents during the study periods. Table 15 presents the percent increase in accident rate by speed limit reduction group. Because of the small number of sites and the small number of accidents that occurred in those sites, no meaningful statistical conclusion can be drawn.

Analysis of Worker and Pedestrian Accident Data. The accident analyses presented here suggest conclusions that, at least for rural freeways, could form a basis for setting work zone speed limit policies. The analysis presented previously, however, does not address one of the specific issues of interest in the study: worker safety.

Both the accident analysis results and the speed variance analysis results suggest that it may be desirable to reduce work zone speed limits by 10 mph; however, consideration must also be given to the question of whether or not a speed limit reduction of 10 mph is adequate to provide for the safety of construction personnel who must work in exposed positions along the traveled way.

There is no information in the literature that indicates what reduction in speed limit or vehicle speed is required to provide for worker safety. The speed analysis results obtained in this study indicate that motorists do slow down more when they are adjacent to active work than when they are not.

The accident data for the 66 work zones in this study were reviewed for any indication of problems related to worker accidents. Because worker accidents cannot be explicitly identified in any of the accident data supplied by the participating states, this analysis focused on pedestrian accidents and accidents involving construction vehicles.

Fourteen pedestrian accidents (3 fatal accidents and 11 injury accidents) occurred on the study sites during the period before construction. In comparison, 24 pedestrian accidents (3 fatal accidents and 21 injury accidents) occurred during construction. This is equivalent to an increase of 29 percent in pedestrian accidents per million vehicle-miles of travel during the construction period. There is no indication that any of these pedestrian accidents involved construction workers and several were explicitly identified by the investigating officer as involving pedestrian violations.

During the construction period, three accidents involved construction vehicles. These accidents, which occurred in three different work zones, each involved collisions between a motorist and construction vehicle that resulted in an injury. There were no fatalities involving construction vehicles.

Although these data do not suggest any major safety problems involving construction workers in the work zones studied, the data do not indicate whether any of the injured parties in the accidents discussed previously were construction workers.

Motorist, Contractor, and Insurance Carrier Surveys

Motorists, construction contractors, and construction liability insurance carriers were surveyed to determine their experiences with and attitudes toward work zone speed limits. The results of the surveys are summarized in the following sections and are presented in more detail in Appendix F, which is not published herein.

Motorist Survey

A survey of motorist attitudes about work zones and speed limits was conducted near three work zones: two in Missouri and one in Georgia. Surveys were conducted at two rest areas and a service station located a few miles downstream of the work zones. Each survey lasted about 2 hours; 58 drivers were interviewed. Because speed data were collected at the respective work zones, the speed distribution from which the sample of drivers interviewed was selected was known. Two work zones had lane closures and the other was off the traveled way at a roadside weigh station. The two-lane closure work zones had the speed limits reduced from 65 to 45 mph and 65 to 40 mph, respectively. The roadside work zone had the speed limit reduced from 65 to 45 mph.

Results of Speed Studies in Work Zones Where Motorists Were Surveyed. Table 16 presents the speed data for the work zones where the motorist surveys were conducted. These data show that drivers reduce their speeds in work zones—but not to the posted speed limit. The percentage of drivers traveling at or below the speed limit in the work zone ranged from 4 to 18 percent. The standard deviation of speeds was higher in the work zone than at the upstream location. The fastest work zone speeds were observed in the roadside work zone.

Results of Motorists Interviews. The survey objectives were to determine whether drivers were aware that they had driven through a work zone; whether they could recall the features of a work zone, including the speed limit; and whether they understood the purpose of work zone traffic control.

Slightly more than one-third (38 percent) of the drivers had driven through the work zone before. About two-thirds of the drivers said that there was something about the work zone that caused them to change their driving. Ninety-one percent of all drivers (53 out of 58) said they saw the speed limit sign or reduced their driving speed or both. Of the 19 drivers who said there was nothing that caused them to change their driving, 14 drivers (74 percent) said they saw a speed limit sign.

Of the drivers at the lane closure sites that were asked about the appropriateness of the reduced speed limit, 73 percent (8 of 11) thought that the reduced speed limit was about right.

At the site where work was off of the traveled way, only 38 percent (3 of 8) thought that the reduced speed limit was about right. The negative respondents thought that the reduced speed limit was inappropriate because there wasn't any work being done that day. (No work was underway on the day of the survey.)

Drivers were shown a list of work zone situations and asked where drivers should reduce their speeds. The primary reasons that motorists thought would justify requiring drivers to reduce their speeds in work zones were workers in the road, lane closures, and stop-and-go traffic because of congestion.

A question was asked to determine if drivers who did not mention having seen the reduced speed limit sign actually knew the posted speed limit. Of those drivers who stated that they knew the speed limit, 76 percent (19 of 25) identified the speed limit correctly.

Ninety percent of the drivers (27 out of 30) in the lane closure work zones thought that a speed limit reduction was justified in that particular work zone; however, only 1 of 4 respondents in the roadside work zone thought that the speed limit reduction was justified.

The results of the motorist survey suggest that speed limit reductions are warranted when workers are in the road or a lane is closed. Some drivers thought that congestion was also a good reason to reduce speeds, but others stated that the congestion itself will reduce speeds. Motorists generally believed that, when work is off of the traveled way or when no work is being conducted, the speed limit should not be reduced.

Most of the drivers (91 percent) stated that they either saw the speed limit sign or reduced their speed or both. About three-quarters of the drivers correctly remembered the speed limit. These positive responses suggest that signing does help to reinforce the speed limit for drivers. Drivers reduced their speed by a greater amount in lane closure work zones than in the roadside work zone. The standard deviations of speeds increased from the open highway to the work area in all three work zones.

The survey results show that drivers have definite beliefs about work zone traffic and will

TABLE 14 Percent increase in accident rate by speed limit reduction group for traveled way and detour work zones on rural two-lane highways

Speed Limit Reduction (mph)	Number of Sites	Mean % increase in	
		Total Accident Rate	Fatal and Injury Accident Rate
0	1	-83.0	—
5	1	60.5	92.6
10	2	56.3	247.2
15	—	—	—
20	5	83.9	2.6
25/30	—	—	—

TABLE 15 Percent increase in accident rate by speed limit reduction group for shoulder and roadside work zones on rural two-lane highways

Speed Limit Reduction (mph)	Number of Sites	Mean % increase in	
		Total Accident Rate	Fatal and Injury Accident Rate
0	—	—	—
10	1	-21.0	12.0
15	2	26.6	-48.5
20	1	-30.9	46.8
25/30	—	—	—

TABLE 16 Vehicle speeds in work zones where drivers were surveyed (mph)

Site	Speed Limits	Mean Speed		Change in Mean Speed	Standard Deviation	
		Open Highway	Work Area		Open Highway	Work Area
MO04F	65/45	61	56	5	5	8
MO02	65/45	69	52	17	5	9
GA04	65/40	68	54	14	5	8

drive according to what they perceive the conditions in the work zone will permit.

Construction Contractor Survey

A survey of ten members of the Montana Contractor's Association was conducted. According to the Association, these firms surveyed performed about 80 percent of the highway construction work in Montana. The types of work done by these contractors include street and highway construction, bridge construction, asphalt, concrete, material supply, signing, pavement marking, lighting, traffic signals, guardrail, and traffic control.

The Montana Department of Highways uses a blanket 35-mph regulatory speed limit for most construction zones. Contractors believe that it is difficult to slow traffic, but that speed limits should be reduced in work zones, perhaps as low as a speed limit of 25 mph.

Contractors also believe that, although the presence of a police officer is effective in slowing traffic in work zones, vehicle speeds increase as soon as the officer leaves. Some contractors stated that police officers are not necessary in work zones, while others stated that officers should only be used for enforcement purposes and not for traffic control. Two contractors stated that flaggers should be given enforcement authority, even to the point of detaining offenders until a police officer arrives on site. One contractor stated that more people would comply with the speed limit if they thought they would be fined for speeding.

Factors for Determining the Need for Reduced Speed Limits. The factors that contractors mentioned most frequently as considerations in determining the need for reduced work zone speed limits were the type of work being performed and the need to perform work in the traveled way. These results suggest that contractors consider reduced speed limits justified when the work interferes with normal traffic flow. Contractors also cited safety of workers and motorists, and high traffic volumes as the reasons for reducing work zone speed limits. Other factors identified by contractors included presence of equipment, area type (e.g., urban or rural), common sense, length of work zone, road type, sight distance, size of work force, and width of road open to traffic.

Effective Speed Control Techniques. The effective speed control techniques that contractors mentioned most frequently were use of flaggers and proper traffic controls. Flashing lights and pilot cars also were mentioned frequently.

These techniques all pertain to traffic controls in the work zone. Use of police officers for speed control was not thought very effective, because speeds increase when the police officers leave the work zone. Contractors believe that established traffic control procedures can be used to control speed. Speed enforcement, including issuing speeding tickets, should supplement the traffic controls as needed.

Montana highway contractors believe that speeds should be reduced in highway work zones. The factors they consider important in establishing speed limits are also the factors considered by state highway agencies. The contractors think that there should be less reliance on police officers for traffic control in work zones. They also believe that work zone personnel should be given expanded authority to control speed in work zones.

Insurance Carrier Survey

Telephone interviews were conducted with selected insurance carriers that provide liability insurance to highway contractors to obtain the views of the carriers on work zone speeds and speed limits. Calls were made to insurance carriers in Connecticut, Minnesota, Nebraska, and Washington.

It was learned that insurance carriers suggest that contractors talk with persons knowledgeable about work zone traffic control or follow state guidelines when reviewing work zone traffic control procedures.

The survey found that insurance carriers do not require or promote reduced work zone speed limits and do not charge lower insurance rates for work zones with reduced speed limits.

CONCLUSIONS

A nationwide survey identified three types of work zone speed limit policies: (1) policies based on avoiding the need for speed limit reductions whenever possible, (2) policies based on blanket speed limit reductions at all work zone sites, and (3) policies under which the need for a work zone speed limit reduction is established on the basis of specific factors. The effectiveness of work zone speed limits was evaluated through accident and operational studies in seven states covering these three types of policies for establishing work zone speed limits. The following roadway types, arranged in decreasing priority, were studied: (1) rural freeway or expressway, (2) urban freeway or expressway, (3) rural multilane or rural two-lane highway, (4) rural two-lane highway detour with free-flow maintained, and (5) urban arterial.

The speed studies showed that motorists reduce speed in work zones—even in work zones with no speed limit reduction. Mean speeds were approximately 5 mph lower within work zones with no speed limit reduction than they were upstream of the same work zones.

Speed limit compliance varied greatly from site to site. In general, compliance was greatest in work zones where the speed limit was not reduced, and compliance decreased where the speed limit was reduced by more than 10 mph.

The speed and accident study confirmed that large speed limit reductions in work zones are undesirable. Speed limit reductions to 10 mph below the preconstruction speed limit resulted in the smallest increase in speed variance within the work zone—relative to the speed variance upstream of the work zone—regardless of any of the speed limit reduction [illegible]. Additionally, in rural freeway work zones involving work on or near the traveled way, a 10-mph reduction in the work zone speed limit minimized the accident rate increase from the preconstruction period to the construction period. The investigators conclude that

- Work zone speed limit reductions should be avoided whenever possible, particularly in work zones where all work activities are located in shoulder or roadside areas and when no work activities are underway.
- A 10-mph reduction below the normal speed limit is desirable as a work zone speed limit when
  - Work takes place on or near the traveled way, particularly on rural freeways,
  - Personnel are required to work for extended periods in an unprotected position within 10 ft of the edge of the traveled way.
- Work zone speed limit reductions larger than 10-mph are undesirable and should be avoided except where required by restricted geometrics or other work zone features that cannot be modified.

Recommended *MUTCD* Revisions

On the basis of the findings of this research, GME has prepared recommended revisions to the *MUTCD*. The additional text would provide a general description of the research findings, which would be suitable for inclusion in other guidelines. GME also prepared a recommended procedure for determining work zone speed limits, which describes the steps that should be taken to properly implement the research findings. Both these sections of the research report are outlined in the following paragraphs.

Part VI of the *MUTCD* addresses the requirements for work zone traffic control. The only portion of Part VI that currently addresses the establishment of work zone speed limits is Section 6A-5 of the 1988 *MUTCD*, which enumerates the fundamental principles of work zone traffic control. The relevant portion of Section 6A-5 states:

> 2. Traffic movement should be inhibited as little as practicable.
>
> a. Traffic control in work and incident sites should be designed on the assumption motorists will only reduce their speeds if they clearly perceive a need to do so. Reduced speed zoning should be avoided as much as practicable.

Based on discussion between the research team and the National Committee on Uniform Traffic Control Devices, no change in these fundamental principles is recommended. The findings of this research identify factors that, if present in a work zone, may warrant a speed limit reduction. However, as implied by the fundamental principles, it would be desirable, whenever possible, to operate work zones that do not require speed limit reductions.

It may be appropriate to incorporate some additional guidance in Part VI of the *MUTCD* that identified engineering factors that may warrant speed limit reductions. Alternatively, such guidance could be incorporated in national guidelines such as the *Traffic Control Devices Handbook* or in guideline documents developed by individual highway agencies. The following text provides a general description of the findings of this research that is suitable for incorporation in a new section of Part VI of the *MUTCD* or in a separate guideline document:

> In accordance with the fundamental principles in *MUTCD* Section 6A-5 that motorists will reduce their speeds only if they perceive a clear need to do so. Reduced speed zoning should be avoided as much as practicable. Speed limit reduction of up to 10 mph from the normal or preconstruction speed limit may be implemented for work zones that involve traffic control devices placed in or very close to the traveled way, particularly on freeways. Speed zones with a reduction in speed limit up to 10 mph may also be appropriate in work zones where workers must work near the traveled way without the protection of a positive barrier for extended periods. Where the use of geometric elements with reduced design speeds cannot be avoided in a work zone, the speed limit should not exceed the design speed. Reduced speed limits should be used only during specific time periods and in the specific portion of the work zone where the factors identified previously are present. Reduced speed zoning should be avoided as much as practicable at sites where all traffic control devices and all work activities are located on the shoulder or in roadside area.

Other *MUTCD* sections that deal with work zone speed limits (e.g., Section 6B-6 which references the specifications for regulatory signing) would not need to be modified.

The research team has developed a recommended procedure for determining work zone speed limits. This procedure is presented in the next section. However, the research team does not recommend that this procedure be included in the *MUTCD*. A detailed procedure of this type is more appropriate for incorporation in handbooks, guidelines, and highway agency policy statements.

Recommended Procedure for Determining Work Zone Speed Limits

This procedure provides a rational method for considering engineering factors in selecting an appropriate work zone speed limit. The framework for the work zone speed limit procedure has been chosen because it provides an excellent method for classifying the work zone situations to which speed limits may be applied. The primary basis for the classification of work zones in this framework is the potential hazard present in the work zone (as represented by location of work activities in relation to the traveled way), rather than the prevailing speed of traffic in work zones. This approach is intended to establish speed limits on the basis of actual conditions in the work zone (that may not be apparent to drivers), rather than prevailing speeds, which are not known during the design stage and may change from day to day as the work progresses and the traffic control is changed accordingly.

On the basis of the present guidance in the *MUTCD*, the procedure starts with a default speed limit equal to preconstruction speed limit at the work site. The preconstruction speed limit is usually, but not necessarily, the same as the speed limit upstream of the work zone during the construction period.

The recommended procedure is based on consideration of speed limits for work zones on a site-by-site basis. Blanket policies—such as those that mandate the reduction of work zone speed limit to a fixed value—regardless of the pre-construction speed limit, the upstream speed limit, or the conditions in the work zone—are not recommended.

The need for a speed limit reduction is determined in the procedure through consideration of a number of factors related to the actual conditions in a specific work zone. At such locations where work activities are removed from the roadway by 10 ft or more, it is recommended that the work zone speed limit not be reduced. When work activities are closer to the roadway and other specific factors are present, speed limit reductions **may** be used. The word "may" is used, because the highway agency, through their design and field engineers, are in the best position to decide if a work zone speed limit reduction is appropriate for the conditions at the work site location.

In each situation where a work zone speed limit reduction may be appropriate, the recommended procedure indicates the maximum speed limit reduction that should be considered. On the basis of research findings from data gathered in work zones in seven states, a work zone speed limit reduction greater than 10 mph is not recommended unless the design speed of a geometric element is more than 10 mph below the normal speed limit.

Reduced speed limits are generally most appropriate for projects that last at least 24 hours, but there is nothing to constrain highway agencies from using reduced work zone speed limits for shorter projects, if appropriate.

Reduced work zone speed limits should be used only during specific periods and only in the specific portion of the work zone where the engineering factors identified in the work zone speed limit procedure are present. In developing work zone traffic control plans for specific sites, consideration also should be given to speed control techniques other than regulatory speed limits. For example, flaggers may be effective in slowing traffic at specific work sites where use of a regulatory speed limit throughout the entire work zone would be inappropriate

Work Zone Speed Limit Procedure

The appropriate speed limit for any highway work zone can be determined from the procedure presented in this section. The procedure is applicable to stationary construction zones, maintenance zones, and utility operations; intermittent moving operations; and continuous moving operations. The recommended procedure has four steps

- Step 1—Determine the existing speed limit,
- Step 2—Determine the work zone condition that applies,
- Step 3—Determine which factors for the appropriate condition apply to the specific site, and
- Step 4—Select the work zone speed limit.

Each step is discussed below. This procedure is illustrated by the flow chart in Figure 3. Figure 4 illustrates the seven work zone conditions that are addressed in Step 2.

Step 1—Determine the existing speed limit

The first step in the procedure is to determine the existing (preconstruction) speed limit for the work zone. The preconstruction speed limit is usually, but not necessarily, the same as the speed limit upstream of the work zone during the construction period. The preconstruction speed limit serves as the default value for the work zone speed limit. The speed limit in the work zone should be reduced only if such a reduction is warranted by the factors considered in the remainder of the procedure.

Step 2—Determine the work zone condition that applies

The work zone **condition** is determined by the location of work activities in relation to the traveled way. In general, speed limit reductions are more appropriate for work zones in which work activities take place in or near the traveled way than for work zones where work activities take place in shoulder or roadside areas well removed from the traveled way or behind a positive barrier.

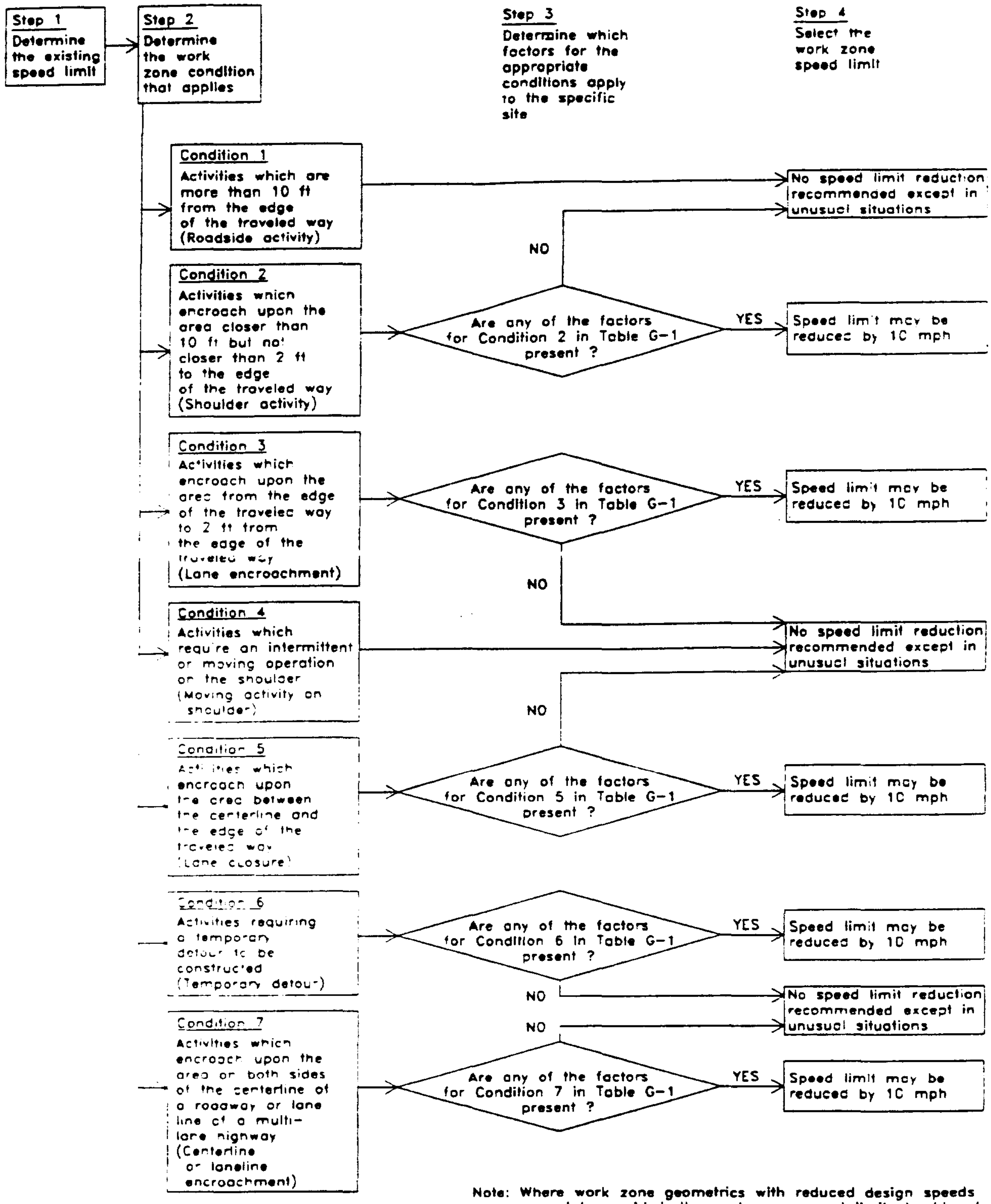
The procedure addresses the following **conditions**:

1. Activities that are more than 10 ft from the edge of the traveled way (roadside activity),
2. Activities that encroach on the area closer than 10 ft but not closer than 2 ft to the edge of the traveled way (shoulder activity),
3. Activities that encroach on the area from the edge of the traveled way to 2 ft from the edge of the traveled way (lane encroachment),
4. Activities that require an intermittent or moving operation on the shoulder (moving activity on shoulder),
5. Activities that encroach on the area between the centerline and the edge of the traveled way (lane closure),
6. Activities that require a temporary detour roadway (temporary detour), and
7. Activities that encroach on the area on both sides of the centerline of a roadway or lane line of a multilane highway (centerline or lane line encroachment).

The conditions are discussed in greater detail later in this section.

Step 3—Determine which factors for the appropriate condition apply to the specific site

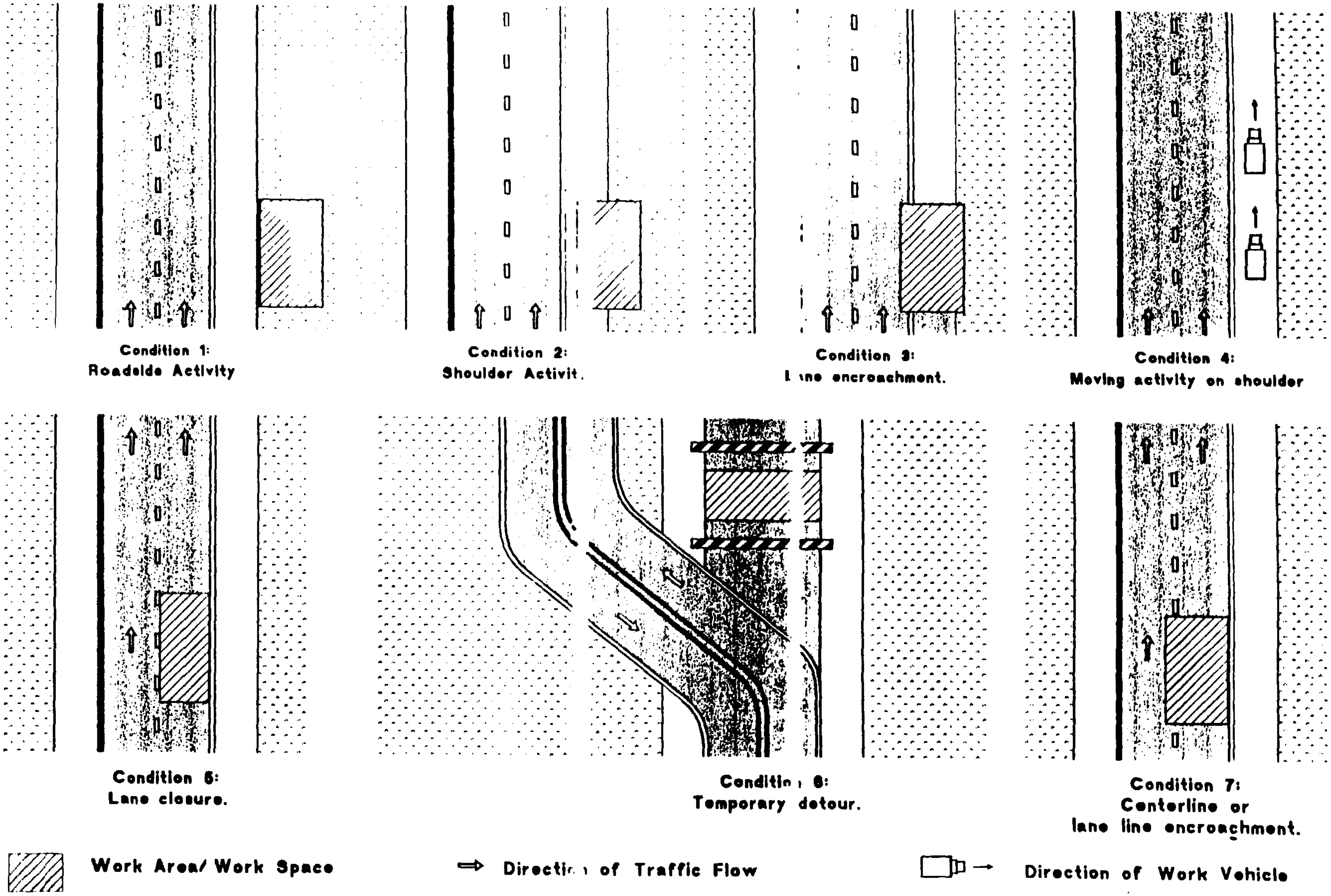
The third step in the procedure is to review the



Note: Where work zone geometrics with reduced design speeds cannot be avoided, the work zone speed limit should not exceed the design speed, even if this requires a speed limit reduction greater than 10 mph.

Figure 3. Work zone speed limit procedure flowchart.

Figure 4. Work zone conditions.



portion of Table 1 applicable to the condition present in the work zone. Table 1 identifies the factors that should be considered in determining whether a speed limit reduction is appropriate for any given work zone condition. If any of the factors identified in the applicable portion of Table 1 is present, then a work zone speed limit reduction is warranted and **may** be implemented. Consideration of the factors in Table 1 is especially important at sites where the presence of these factors may not be apparent to motorists.

Step 4—Select the work zone speed limit

The work zone speed limit should be selected considering the factors presented in Table 1. The table includes guidelines on the maximum speed limit reduction that is recommended for each work zone condition. Speed limit reductions larger than the recommended 10-mph maximum should generally be considered only if restricted geometrics with a lower design speed are present in the work zone and modification of the geometrics to a higher design speed is not feasible.

Highway engineers responsible for each work zone should monitor the conditions in the work zone and ensure that the posted speed limit is appropriate for the actual conditions at any given time. For example, the presence of workers in an unprotected position within 10 ft of the traveled way for an extended period of time warrants a speed limit reduction of 10 mph. However, if worker protection is the only warrant for a speed limit reduction, the speed limit should be restored to its original value when the work activity at that location is completed. Use of work zone speed limits that are appropriate for the conditions that actually exist in the work zone is very important in maintaining motorists respect for speed limits. If motorists frequently encounter reduced speed limits that are not appropriate for the actual conditions in the work zone, they may lose respect for all speed limits and, thus, choose a speed that is too high in a situation where reduced speeds are truly necessary.

All work zone traffic controls should be evaluated at the beginning of the project and periodically through the life of the project to determine if the traffic controls are operating as intended. If problems, including traffic accidents, evidence of traffic accidents, such as debris, or near misses are occurring, the responsible person (resident engineer or traffic control specialist) should determine the cause of the problems so that the circumstances causing the problems can be corrected. Correction may require assistance from the traffic control designer, traffic engineer, or other knowledgeable person.

Condition 1

Activities that are more than 10 ft from the edge of the traveled way (roadside activity)

Typical Applications

Roadway construction
Cleaning drainage
Landscaping work
Structural work
Utility work
Reworking ditches
Fencing work

Reductions to Existing Regulatory Speed Limit

Should not be used*

Suggested Maximum Amount of Speed Reduction

None

Factors

None

The regulatory speed limit shall meet all requirements of the *MUTCD*.

*There should not be a reduction to the existing regulatory speed limit unless unusual situations create hazardous conditions for motorists, pedestrians, or workers.

Condition 2

Activities that encroach on the area closer than 10 ft but not closer than 2 ft to the edge of the traveled way (shoulder activity)

Typical Applications

Roadway construction
Culvert extensions
Guardrail installation
Cleaning drainage
Reworking ditches
Shoulder work
Utility work
Side slope work
Landscaping work
Structural work
Sign installation

Reductions to Existing Regulatory Speed Limit

May be used where **Factors** exist

Suggested Maximum Amount of Speed Reduction

10 mph

Factors

- Workers present for extended periods within 10 ft of traveled way unprotected by barriers
- Horizontal curvature that might increase vehicle encroachment rate (could include mainline curves, ramps, and turning roadways)

The regulatory speed limit shall meet all requirements of the *MUTCD*.

Condition 3

Activities that encroach on the area from the edge of the traveled way to 2 ft from the edge of the traveled way (lane encroachment)

Typical Applications

Roadway construction	Utility work
Guardrail installation	Shoulder work

Reductions to Existing Regulatory Speed Limit

May be used where **Factors** exist

Suggested Maximum Amount of Speed Reduction

10 mph

Factors

- Workers present for extended periods within 2 ft of traveled way unprotected by barrier
- Horizontal curvature that might increase vehicle encroachment rate (Could include mainline curves, ramps, and turning roadways.)
- Barrier or pavement edge dropoff within 2 ft of traveled way
- Reduced design speed for stopping sight distance
- Unexpected conditions

The regulatory speed limit shall meet all requirements of the *MUTCD*. Where work zone geometrics with reduced design speeds cannot be avoided, the work zone speed limit should not exceed the design speed, even if this requires a work zone speed limit reduction greater than 10 mph.

Condition 4
Activities that require an intermittent or moving operation on the shoulder (moving activity on shoulder)

Typical Applications
Roadway construction
Widening
Delineator installation
Shoulder and slope work
Utility work
Guardrail installation
Landscape work

Reductions to Existing Regulatory Speed Limit
Should not be used*

Suggested Maximum Amount of Speed Reduction
None

Factors
None

The regulatory speed limit shall meet all requirements of the *MUTCD*.

*There should not be a reduction to the existing regulatory speed limit unless unusual situations create hazardous conditions for motorists, pedestrians, or workers.

Condition 5
Activities that encroach on the area between the centerline and the edge of traveled way (lane closure)

Typical Applications
Roadway construction
Pavement repair
Utility work
Widening
Pavement resurfacing
Pavement marking
Bridge repair

Reductions to Existing Regulatory Speed Limit
May be used where **Factors** exist

Suggested Maximum Amount of Speed Reduction
10 mph

Factors
- Workers present for extended periods in the closed lane unprotected by barrier
- Lane width reduction of 1 ft or more with a resulting lane width less than 11 ft
- Traffic control devices encroaching on a lane open to traffic or within a closed lane but within 2 ft of the edge of the open lane
- Reduced design speed for taper length or speed change lane length
- Barrier or pavement edge dropoff within 2 ft of the traveled way
- Reduced design speed of horizontal curve
- Reduced design speed for stopping sight distance
- Traffic congestion created by a lane closure
- Unexpected conditions

The regulatory speed limit shall meet all requirements of the *MUTCD*. Where work zone geometrics with reduced design speeds cannot be avoided, the work zone speed limit should not exceed the design speed, even if this requires a work zone speed limit reduction greater than 10 mph.

Condition 6

Activities requiring a temporary detour to be constructed (temporary detour)**

Typical Applications

Roadway construction
Subgrade restoration
Bridge construction
Culvert repair

Reductions to Existing Regulatory Speed Limit

May be used where **Factors** exist

Suggested Maximum Amount of Speed Reduction

10 mph

Factors

- Lane width reduction of 1 ft or more with a resulting lane width less than 11 ft
- Reduced design speed for detour roadway or transitions (radius of curvature, superelevation, and sight distance)
- Unexpected conditions

The regulatory speed limit shall meet all requirements of the *MUTCD*. Where work zone geometrics with reduced design speeds cannot be avoided, the work zone speed limit should not exceed the design speed, even if this requires a work zone speed limit reduction greater than 10 mph.

**Detour and transition geometry with a design speed equal to or greater than the existing regulatory speed limit should be provided whenever possible.

Condition 7

Activities that encroach on the area on both sides of the centerline of a roadway or lane line of a multilane highway (centerline or lane line encroachment)

Typical Applications

Roadway construction
Pavement marking
Pavement resurfacing
Pavement repair
Widening
Crack sealing
Bridge repair

Reductions to Existing Regulatory Speed Limit

May be used where **Factors** exist

Suggested Maximum Amount of Speed Reduction

10 mph

Factors

- Workers present on foot in the traveled way or in the closed lane unprotected by barrier for extended periods
- Remaining lane plus shoulder width is less than 11 ft
- Reduced design speed for taper length or speed change lane length
- Barrier or pavement edge dropoff within 2 ft of the traveled way
- Reduced design speed of horizontal curve
- Reduced design speed for stopping sight distance
- Traffic congestion created by lane closure
- Unexpected conditions

The regulatory speed limit shall meet all requirements of the *MUTCD*. Where work zone geometrics with reduced design speeds cannot be avoided, the work zone speed limit should not exceed the design speed, even if this requires a work zone speed limit reduction greater than 10 mph.

DEFINITIONS OF WORK ZONE CONDITIONS

This section presents a discussion of the seven work zone conditions included in Table 1 that are considered in selecting an appropriate work zone speed limit.

Condition 1—Roadside Activity

The first condition relates to activities that are more than 10 ft from the edge of the traveled way. These operations are outside of the edge of the shoulder and typically include landscaping work, fencing, and ditching.

The report recommends that the speed limit should not be reduced for this condition. If all work activities are 10 ft or more from the edge of the traveled way, there should be no interference with traffic flow and minimal risk to workers on the roadside.

Condition 2—Shoulder Activity

This condition addresses activities that are less than 10 ft but more than 2 ft from the traveled way. Such work activities encroach on the shoulder but not on the traveled way. These activities have an effect on traffic but not as much effect as activities at the edge of the traveled way. Typical applications include culvert extensions, guardrail, structural work, and shoulder repair.

The report recommends that the speed limit should not be reduced for this condition; however, the speed limit may be reduced if one or more factors listed for this condition in Table 1 are present. The maximum speed limit reduction recommended for this condition is 10 mph, unless geometric design features require a larger speed limit reduction.

Highway agencies may choose to implement work zone speed limit reductions for this condition if the listed factors are present. In particular, a speed limit reduction may be considered if unprotected workers are present for an extended period within 10 ft of the traveled way.

Other than worker safety, for which no previous research was found, the factors recommended for consideration as part of this condition (and for the other conditions) are supported by research that documents their safety and operational effects. These include horizontal curvature and unexpected conditions within the work zone.

Horizontal curvature that might increase the vehicle encroachment rate constitutes another important factor that may be considered for shoulder work. Mainline curves and curves on ramps and turning roadways may each be considered. Consideration should include existing curves and curves introduced because of the construction activity. Shoulder areas adjacent to sharp horizontal curves are in many cases subject to run-off-the-road accidents, as evidenced by the amount of damaged guardrail and guardrail repair work at these locations. Any shoulder or roadside work in these areas is potentially subject to the same kind of accidents. Reduction of the work zone speed limit is warranted if the design speed of the horizontal curve is less than the existing speed limit.

Unexpected conditions within the work zone may also warrant a reduction in the work zone speed limit. For example, if construction equipment movements interfere with traffic, a reduction in the work zone speed limit may be warranted. However, if these movements occur during particular portions of the construction work, the speed limit reduction would be appropriate only during those portions of the work.

Condition 3—Lane Encroachment

A third work zone condition involves activities that encroach on the area from the edge of the traveled way to 2 ft from the edge of the traveled way. Thus, these activities are on the roadway shoulder very close to the traveled way. Typical activities for this condition are utility work, guardrail maintenance, and shoulder work.

The maximum speed limit reduction recommended for this condition is 10 mph, unless geometric design features require a larger speed limit reduction. Several factors, in addition to those of the previous condition, could warrant a reduced speed limit. As for Condition 2, the presence of unprotected workers, horizontal curvature, and unexpected conditions could each indicate the need for a reduced speed limit. The presence of unprotected workers within 2 ft of the traveled way would be an even stronger indication of the need for a reduced speed limit than it was for Condition 2 where the workers might be further from the roadway. Other factors that could warrant a speed limit reduction are the presence of a barrier, a pavement edge dropoff, or inadequate stopping sight distance.

Research has shown that a barrier within 2 ft of the edge of the traveled way reduces vehicle speeds and increases the likelihood that vehicles will shy away from the barrier. A pavement edge dropoff delineated with drums or other devices will have the same effect. Furthermore, a pavement edge dropoff presents a hazard to motorists who leave the roadway or try to return to it and this potential hazard typically increases with vehicle speed. Thus, the presence of a pavement edge dropoff may warrant a reduced speed limit when the dropoff is present.

The presence of limited stopping distance that does not meet the AASHTO Green Book criteria for a design speed equal to the existing speed limit is another justification for a speed limit reduction when work activities occur within 2 ft of the roadway. The presence of limited sight distance increases the possibility that a driver may be unable to see a stopped vehicle entering a roadway or an object in the roadway in time to stop. A driver who cannot stop is likely to attempt to avoid a collision by leaving the roadway, thus increasing the likelihood of entering the work area. This risk could be mitigated by reducing the speed limit—assuming that drivers would reduce their speeds in compliance with that speed limit.

Condition 4—Moving Activity on Shoulder

Activities requiring continuous or intermittent moving on the shoulder are beyond the scope of accident and field studies conducted for this research. This condition was included, however, to make the recommended procedure as complete as possible. No regulatory speed limit reduction is recommended for this condition.

Condition 5—Lane Closure

Activities that encroach on the area between the centerline or lane line and the edge of the traveled way, such as lane closures, are very critical because they directly interfere with existing traffic patterns.

A maximum speed limit reduction of 10 mph is recommended for Condition 5 sites, as it was recommended for Condition 3. A 10-mph speed limit reduction is desirable for work zones on rural freeways and may also be appropriate for other roadway types. Speed limit reductions greater than 10 mph are recommended only if required by restricted geometrics.

Most of the factors that may warrant speed limit reductions at lane closure sites (including the presence of unprotected workers, roadside barrier, pavement edge dropoffs, horizontal curvature, limited stopping sight distance, and unexpected conditions) have been discussed previously.

Taper and speed change lane lengths are critical geometric elements that should be designed to the speed limit or prevailing speed. In situations where it is not physically possible to do this, however, a reduced work zone speed limit may be warranted.

Traffic congestion created by a lane closure is another factor that may warrant a speed limit reduction. Traffic backups because of a decreased capacity of the roadway may lead to rear-end accidents. Traffic traveling at slower speeds will have more time to react to the rapidly slowing traffic immediately ahead. The presence of congestion, however, may provide greater justification for speed limit reduction upstream of the lane closure (where a standing queue may be present) than in the work zone itself.

Condition 6—Temporary Detour

Activities requiring temporary detours may warrant a reduced work zone speed limit of 10 mph below the existing speed limit. Where a detour roadway is provided, the speed limit in the detour should be appropriate for the design speed of the geometry of the detour roadway and the transition areas to and from the existing roadway. Geometric elements that should be considered include lane widths, horizontal curvature, and stopping sight distance. It is desirable to design the detour and transition areas to operate at the existing speed limit. Where this is not possible and the detour or transition areas must be designed for a lower speed, a reduced speed limit should also be used.

The presence of workers has not been listed as a factor to warrant a reduced speed limit on a detour roadway. A major objective of providing a detour roadway is to remove the traffic from the work area. Workers would be expected to be present only for very short periods (for example, when placing traffic control devices).

Condition 7—Centerline or Lane Line Encroachment

Activities that encroach on both sides of a centerline or lane line are considered in Condition 7. These include stationary activities that a lane and encroach on an adjacent lane or stationary activities that involve unprotected workers on foot in the traveled way. Moving operations, such as pavement marking, could also be considered as part of Condition 7. Moving operations, however, are beyond the scope of the accident and field studies conducted for this research. Regulatory speed limit reductions of up to 10 mph are recommended for this condition if workers are present on foot in the traveled way or in the closed lane unprotected by a barrier for extended periods, if the remaining lane and shoulder width is less than 11 ft, or if other unexpected conditions are present. The other factors listed for Condition 5 that justify a regulatory speed limit reduction also apply to Condition 7.

EXAMPLE APPLICATIONS OF THE WORK ZONE SPEED LIMIT PROCEDURE

Six examples that illustrate the application of the work zone speed limit procedure are presented herein.

Example 1

A truck weigh station on a rural, four-lane freeway is being reconstructed and is currently closed. The speed limit on that section of highway is 65 mph. The construction activity in the weigh station is well removed from the traveled way. Construction vehicles entering and exiting the weigh station use the existing ramps to and from the freeway.

1. **Determine the existing speed limit**
   The existing speed limit is 65 mph.
2. **Determine the work zone condition that applies**
   Because the work activity occurs off of the roadway, Condition 1 applies.
3. **Determine the applicable factors**
   Table 1 shows that there are no factors that apply to Condition 1.
4. **Select the work zone speed limit.**
   Because there are no factors that apply to Condition 1, the work zone speed limit should remain at 65 mph.

Example 2

The same work zone described previously in Example 1 periodically requires fill material to be delivered to the work site. Dump trucks transport fill material from a borrow pit that is located a few miles from the work site. The borrow pit is located 300 ft from the roadway and is reached by a temporary road. The dump trucks receive a load of material and drive directly onto the traveled way through an opening in the right-of-way fence and transport the material to the work site.

1. **Determine the existing speed limit**
   The existing speed limit is 65 mph (see Example 1).
2. **Determine the work zone condition that applies**
   Condition 1 applies.
3. **Determine the applicable factors**
   There are no factors in Table 1 for Condition 1; however, slow-moving dump trucks entering the roadway create an unexpected condition for motorists, who may have to brake, change lanes, or swerve to avoid the dump trucks.
4. **Select the work zone speed limit**
   Because of the unexpected occurrence of a slow-moving dump truck entering the traveled way, a reduction in the work zone speed limit by 10 mph is warranted. The highway agency may reduce the speed limit from 65 mph to 55 mph. The reduced speed limit, however, should only be applied when dump trucks are delivering fill material to the work site. Under direction of the resident engineer, the 55-mph speed limits signs should be covered or removed when fill material is not being delivered.

Example 3

A six-lane-urban freeway is being resurfaced. The work activity requires lanes to be closed. The paving machine and channelizing devices frequently encroach into the adjacent lane. In addition to the equipment operators, there are a number of workers on foot in the closed lane. Throughout the day, dump trucks bringing paving material enter and leave the closed lane. The existing speed limit is 55 mph.

1. **Determine the existing speed limit**
   The existing speed limit is 55 mph.
2. **Determine the work zone condition that applies**
   Because a lane closure is required, **Condition 5** applies.
3. **Determine the applicable factors**
   The following factors from Table 1 apply:
   - Workers present in closed lane unprotected by barrier
   - Traffic control devices encroaching on the open lane

   In addition, the factors related to traffic congestion, lane width reduction, and unexpected conditions may also apply.
4. **Select the work zone speed limit**
   Because of the factors present in the work zone, a 10-mph speed limit reduction is warranted. The highway agency may reduce the work zone speed to 45 mph.

Example 4

The same resurfacing project described previously in Example 3 is governed by a contract clause that requires the contractor to reopen all lanes and remove all equipment from the roadway at the end of each working day. The work zone speed limit is reduced to 45 mph during the time work is in progress in the traveled way. What should the speed limit be set at when work is **not** in progress?

1. **Determine the existing speed limit**
   In this example, the existing speed limit refers to the preconstruction speed limit of the highway, which is 55 mph.
2. **Determine the work zone condition that applies**
   Because equipment is required to be stored off of the roadway when work is not progress, **Condition 1** applies.
3. **Determine the applicable factors**
   No factors apply to this condition.
4. **Determine the work zone speed limit**
   The 45-mph speed limit signs should be covered or removed when work is not in progress and replaced with 55-mph speed limit signs. At the start of the next work day, the 45-mph speed limit should be reactivated.

Example 5

The same work zone referred to in Examples 3 and 4 is experiencing minor rear-end accidents and many near misses on the approach to the lane closure areas because of congestion caused by the reduction in capacity created by the lane closure. The traffic backup often extends into the advance warning area beyond the reduced speed limit signs.

1. **Determine the existing speed limit**
   The existing speed limit in this case is 45 mph.
2. **Determine the work zone condition that applies**
   As in Example 3, **Condition 5** applies to this work zone.
3. **Determine the applicable factors**
   Traffic congestion caused by a lane closure is one additional factor that may apply.
4. **Select the work zone speed limit**
   Example 3 shows that lane closure work zones warrant a 10-mph speed limit reduction; in this case, the speed limit should be reduced from 55 mph to 45 mph. The presence of traffic congestion upstream of the lane drop taper is also a factor in Table 1 that warrants a 10-mph speed limit reduction. Because the 45-mph speed limit is already in place during the work period, the traffic congestion warrants extending that 45-mph speed limit further upstream beyond the end of the standing queue. In this way, motorists approaching the work zone will receive advance warning of the reduced speed limit before reaching the congested area.

Example 6

A bridge on a rural, two-lane highway is being replaced with a new bridge at the same location. A temporary bridge is being constructed adjacent to the existing bridge. The existing speed limit is 55 mph. The highway agency plans to build a temporary roadway to detour traffic onto the temporary bridge.

The highway agency would like to design the geometrics of the temporary roadway using a 60-mph design speed (to make the retention of a 55-mph speed limit appropriate), but the physical constraints of the site will only permit the roadway to be built at a 50-mph design speed.

1. **Determine the existing speed limit**
   The existing speed limit is 55 mph.
2. **Determine the work zone condition that applies**
   Because a temporary detour is to be constructed, **Condition 6** applies.
3. **Determine the applicable factors**
   The reduced design speed of the temporary roadway is a factor in Table 1 that warrants a reduced work zone speed limit for Condition 6.
4. **Select the work zone speed limit**
   Because the temporary detour will be built to a 50-mph design speed, the work zone speed limit should be reduced by 10 mph (from the existing 55-mph speed limit) to 45 mph.

FINAL REPORT

The overall objectives, research approach, findings, conclusions, and recommendations are presented in the main body of the agency final report for NCHRP Project 3-41 titled "Procedure for Determining Work Zone Speed Limits." Detailed descriptions of the surveys, procedures, analysis results, and final recommendations are presented in the Appendixes. Appendix A presents the literature review; Appendix B, the state highway agency work zone speed limit polices and guidelines; Appendix C, the data collection procedures; Appendix D, the speed data analysis results; Appendix E, the accident data analysis results; Appendix F, the motorist, contractor, and insurance carrier surveys; and Appendix G, the recommended procedure for determining work zone speed limits.

This agency report for Project 3-41 will not be published in the regular NCHRP report series. However, loan copies of the agency report are available by contacting: Transportation Research Board, National Cooperative Highway Research Program, 2101 Constitution Avenue, N.W., Washington, DC 20418.

ACKNOWLEDGMENTS

The research summarized herein was performed under NCHRP Project 3-41 by GME. The subcontractor to GME was the Engineering and Statistical Sciences Section, Midwest Research Institute. James Migletz, Vice President, GME, was the principal investigator. The other authors of the report are Jerry L. Graham, President, GME, and Project Engineer for this research, and Douglas W. Harwood, Principal Traffic Engineer, Midwest Research Institute. Other staff members who contributed to the research include Joseph M. Meehan, Robert L. Massey, Bobbie Bryant-Fields, and James J. Migletz. The work at the Midwest Research Institute was done under the supervision of Mr. Harwood with the assistance of Ms. Karin Bauer, Principal Statistician.

The staffs of seven state highway agencies located in California, Florida, Georgia, Iowa, Missouri, Montana, and New York made substantial contributions in the speed and accident data collection effort. The agencies discussed their work zone speed limit policies and procedures, identified active candidate construction zones, provided names of contact persons at each work zone, and provided computerized listings of traffic accidents during the period when work was being conducted and for an equal period before work began.

The staffs of highway agencies in Idaho, Maryland, Ohio, Texas, and Washington contributed by discussing their work zone speed limit policies and procedures.

We are also grateful to the 45 state and local traffic engineers who responded to a questionnaire on work zone speed limit policies and procedures.

The members of the NCHRP Project 3-41 panel must also be acknowledged for their role in defining and monitoring this research effort. The panel consists of the following members:

Raymond M. Gardeski	Kenneth N. Morefield
Stephen B. Dearing	Jonathan Upchurch
John Hodgkins	James W. Van Sistine
Sanford P. Lahue	J. Richard Young, Jr.
Virginia M. Lorenz	Howard H. Bissell

REFERENCES

1. U.S. Department of Transportation, *Manual on Uniform Traffic Control Devices for Streets and Highways*, Washington, DC, 1988.

2. Federal Highway Administration, "Synthesis of Safety Research Related to Traffic Control and Roadway Elements," Vol. 2, *Report No. FHWA -TS-82-233*, Washington, DC, December 1982.

3. National Committee on Uniform Traffic Laws and Ordinances, *Uniform Vehicle Code and Model Traffic Ordinance*, Washington, DC, 1968 and subsequent revisions.

4. Homburger, W., Editor, *Transportation and Traffic Engineering Handbook*, Prentice-Hall, Englewood Cliffs, New Jersey, 1982.

5. Rowan, N.L., and C.J. Keese, "A Study of Factors Influencing Traffic Speeds," Research Project No. 17, Texas Transportation Institute, College Station, Texas, September 1961.

6. Solomon, D., "Accidents on Main Rural Highways Related to Speed, Driver and Vehicle, Federal Highway Administration, Washington, DC, 1964 (reprinted April 1974).

7. Cirillo, J.A., "Interstate System Accident Research Study II, Interim Report II," *Public Roads*, Vol 35, No. 3, August 1968.

8. ITE Technical Committee 3C, "An International Report on Speed Zoning," *Traffic Engineering*, Vol. 31, No. 10, July 1961, pp. 39-44

9. Wenger, D.M., "Effects of Revising Urban Speed Limits," St., Paul Department of Public Works, St. Paul, Minnesota, June 1960.

10. Ogawa, T., E.S. Fisher, and J.C. Oppenlander, Driver Behavior Study—Influence of Speed Limits on Spot Speed Characteristics in a Series of Contiguous Rural and Urban Areas, *Bulletin 341*, Highway Research Board, National Research Council, Washington, DC, 1962, pp. 18-29

11. Koziol, J., Jr., A.R. Fulchino, P.H. Mengert, and G. Stewart, "Effectiveness of Speed Control Signs in Rural School Zones and Small Communities, *Report No. FHWA-RD-79-20*, Federal Highway Administration, Washington, DC, July 1979.

12. Roberts, R.R., "The Influence of Speed Limits on Urban Speed Distribution Parameters," *Traffic Engineering*, Vol. 38, No. 3, December 1967.

13. Kessler, W.L., "The Effect of Speed Zone Modifications Occasioned by the Illinois Speed Law," *Traffic Engineering*, Vol. 29, No. 10, July 1959.

14. Elmberg, C.M., and H.L. Michael, Effect of Speed Limit Signs on Speed on Suburban Arterial Streets, *Bulletin 303*, Highway Research Board, National Research Council, Washington, DC, 1961, pp. 1-9.

15. Baerwald, J.E., "The Influence of Speed and Speed Regulations on Traffic Flow and Accidents," *International Road Safety and Traffic Review*, Vol. 9, No. 1, Spring 1961.

16. Wiley, C.C., et al., "Effect of Speed Limit Signs on Vehicular Speeds," Department of Civil Engineering, University of Illinois, September 1949.

17. Vayda, A., and I. Crepsi, "Public Acceptability of Highway Safety Counter Measures," *Report No. DOT HS 805 970 through 974*, National Highway Traffic Safety Administration, Washington, DC, June 1981.

18. Fieldwick, R., "The Relationship Between Rural Speed Limit and Accident Rate," *Report No. RF/1/81*, National Institute for Transport and Road Research, South Africa, January 1981.

19. Jeffcoate, G.O., "World Survey of Current Research and Development on Roads and Road Transport: Effect of Speed Limits on Road

Safety in Europe," International Road Federation, 1969.

20. Hearne, R., "International Symposium on the Effects of Speed Limits on Traffic Accidents and Transport Energy Use: Car and Truck Speeds Related to Road Traffic Accidents in the Irish National Road System," Organization for Economic Cooperation and Development, Paris, October 1981.

21. Parker, M.R., Jr., "Synthesis of Speed Zoning Practices," *Report No. FHWA/RD-85/096*, Federal Highway Administration, Washington, DC, July 1985.

22. Harkey, D.L., H.D. Robertson, and S.E. Davis, Assessment of Current Speed Zoning Criteria, *Transportation Research Record 1281*, Transportation Research Board, Washington, DC, 1990.

23. Tignor, S.C., and D.L. Warren, "Speed Zoning in America: Some Preliminary Research Results," Federal Highway Administration, Washington, DC, June 1989.

24. Joscelyn, K.B., R.K. Jones, and P.A. Elston, "Maximum Speed Limits: Volume I—A Study for the Selection of Maximum Speed Limits," *Report No DOT-HS-800-378*, National Highway Traffic Safety Administration, Washington, DC, October 1970.

25. McLeod, D.S., The Optimal Speed Limit: A New Approach, *Transportation Research Record 887*, Transportation Research Board, Washington, DC, 1982.

26. Garber, J.J., and Gadirau, R., "Speed Variance and Its Influence on Accidents," AAA Foundation for Traffic Safety, Washington, DC, July 1988.

27. "The Life-Saving Benefits of the 55 MPH National Speed Limit," NHTSA/FHWA Task Force, *Report No., DOT-HS-805-559*, National Highway Traffic Safety Administration, Washington, DC, October 1980.

28. American Association of State Highway and Transportation Officials, "Effect of Raising the Speed Limit to 65 MPH," Washington, DC, July 20, 1989.

29. Heckard, R.F., J.A. Pachuta, and F.A. Haight, "Safety Aspects of the National 55 MPH Speed Limit," *Report No. FHWA-RD-76-191*, Federal Highway Administration, Washington, DC, November 1976.

30. O'Day, D.M., and D. Golomb, "Study on the Effects of the Energy Crisis and 55 MPH Speed Limit in Michigan," Highway Safety Research Institute, University of Michigan, April 1975.

31. Labrum, W.D., "The 55 MPH Speed Limit and Fatality Reduction in Utah," *Traffic Engineering*, Vol. 46, No. 9, September 1976.

32. Michaels R., and C. Schneider, "The Energy Crisis, Characteristics of Traffic Flows and Highway Safety," *Accident Analysis and Prevention*, Vol. 8, December 1976.

33. Byrne, B.F. and R.R. Roberts, Effect of 55-MPH Speed Limit on Average Speed of Free-Flowing Automobiles on an Interstate Bridge in West Virginia, *Transportation Research Record 538*, Transportation Research Board, Washington, DC, 1975, pp. 69-74.

34. Council, F.M., L. Pilts, M. Sadof, and O.K. Dart, "An Examination of the Effects of the 55 MPH Speed Limit on North Carolina Accidents," Highway Safety Research Center, University of North Carolina, April 1975.

35. Lyles, R.W., "An Evaluation of Warning and Regulatory Signs for Curves on Rural Road," *Report No. FHWA/RD-80/009*, Federal Highway Administration, Washington, DC, March 1980.

36. Ritchie, M.L., "Choice of Speed in Driving Through Curves as a Function of Advisory Speed and Curve Signs," *Human Factors*, Vol. 14, No. 6, December 1972.

37. Bezkorovainy G., and C.C. Hi, "The Influence of Horizontal Curve Advisory Speed Limits on Spot-Speeds," *Traffic Engineering*, Vol. 36, No., 12, September 1966.

38. Graham, J.L., R.J. Paulsen, and J.C. Glennon, "Accident and Speed Studies in Construction Zones," *Report No. FHWA-RD-77-80*, Federal Highway Administration, Washington, DC, June 1977.

39. Hanscom. F.R., "Effectiveness of Changeable Message Displays in Advance of High-Speed Freeway Lane Closures," *NCHRP Report No. 235*, Transportation Research Board, Washington. DC. September 1981.

40. Webb. R.J., "The Effect of an Advisory Speed Signal on Motorway Traffic Speeds," *Report SR 615*. Transport and Road Research Laboratory, Crowthorne, England, 1980.

41. Carter E.C., and R.P Jain, "Establishing Criteria for Speed Limits in School Zones," Engineering Experiment Station, West Virginia University, 1967.

42. "School Speed Limit Experimental Sign Program," Traffic and Transportation Division, City of Seattle, Washington, 1974.

43. Koziol, J., Jr., A.R. Fulchino, P.H. Mengert, and G. Stewart, "Effectiveness of Speed Control Signs in Rural School Zones and Small Communities. *Report No. FHWA-RD-79-20*, Federal Highway Administration, Washington, DC, July 1979.

44. Zegeer, C.V., "The Effectiveness of School Signs with Flashing Beacons in Reducing Vehicle Speeds," *Research Report No. 429*, Kentucky Bureau of Highways, July 1975.

45. McCoy, P.T., A.K. Mohaddes, and R.J. Haden. Effectiveness of School Speed Zones and Their Enforcement. *Transportation Research Record 811*. Transportation Research Board, Washington, DC, 1981, pp. 1-7.

46. Haden, R.J., "Reduced Speed Zones Adjacent to School: A Report of the School Zones," Engineering Experiment Station, West Virginia University, 1967.

47. McCoy, P.T., Heimann, J.E., School Speed Limits and Speeds in School Zones. *Transportation Research Record 1254*, Transportation Research Board, Washington, DC, 1990.

48. Matthews, M.L., "Impact of Highway Metrication on Traffic Accidents and Long-Term Trends in Vehicle Speeds for Roads with Resultant Increased Speed Limits," *Human Factors*, Vol. 21, No. 4, August 1979.

49. Reiss, M.L., and H.D. Robertson, Driver Perception of School Traffic Control Devices (abridgement), *Transportation Research Record 600*, Transportation Research Board Washington, DC 1976, pp. 36-39.

50. Sparks, J.W. and M.J. Cynecki, "Pedestrian Warning Flashers in an Urban Environment Do They Help?" *ITE Journal*, Vol. 60, No. 1 January 1990, pp. 32-36.

51. Burritt, B.E., R.C. Buchanan, and E.I Kalivoda, "School Zone Flashers—Do They Really Slow Traffic?" *ITE Journal*, Vol. 60 No. 1, January 1990, pp. 29-31.

52. North Carolina Department of Transportation "Work Zone Speed Study," Letter to James Migletz dated January 22, 1990.

53. Richards, S.H., M.J.S. Falkner, and C.L Dudek, "Traffic Management During Freeway Reconstruction and in Rural Work Zones," *Report No. 263-7F*, Texas Transportation Institute, College Station, Texas, October 1982

54. Jackels, J. and D. Brannon, "Work Zone Speed Limit Study on Rural I-35 in Minnesota," Minnesota Department of Transportation, Office of Traffic Engineering, St. Paul, Minnesota November 1988.

55. Benekohal, R.F. et al., Speed-Reduction Patterns of Vehicles in a Highway Construction Zone, *Transportation Research Record 1352*, Transportation Research Board, Washington, DC, 1992, pp. 35-45.

56. Richards, S.H., et al., "Improvements and New Concepts for Traffic Control in Work Zones, Volume Speed Control in Work Zones," *Report No. FHWA/RD-85/037*, Federal Highway Administration, Washington, DC, September 1985.

57. Richards S.H. and C.L. Dudek, Implementation of Work Zone Speed Control Measures, *Transportation Research Record 1086*, Transportation Research Board, Washington, DC, 1986.

58. Missouri Highway and Transportation Department, "Safety in the Work Zone—Radar Controlled Speed Matrix Signs," Jefferson City, Missouri, 1988.

59. Noel, E.C., Z.A. Sabra, and C.L. Dudek, "Use of Rumble Strips in Work Zones," *Report No. FHWA-TS-89-037*, Federal Highway Administration, Washington, DC, May 1989.

60. Richards, S.H., R.C. Wunderlich, and C.L. Dudek, Field Evaluation of Work Zone Speed Control Techniques, *Transportation Research Record 1035*, Transportation Research Board, Washington, DC, 1985, pp. 66-78.

61. Pigman, J.G., and K.R. Agent, "Evaluation of I-75 Lane Closures," *Report No. UKTRP-86-19*, Kentucky Transportation Cabinet, Frankfort, Kentucky, August 1986 (cited in Ref. 59).

62. AKT Corporation, "AKT Temporary Rumble Strips," Wauwatosa, Wisconsin, not dated, (cited in Ref. 59).

63. Ohio Department of Transportation, "Rumble Strips," unpublished memorandum, October 21, 1987 (cited in Ref. 59).

64. Booker, S.C., et al. Supplemental Devices to Enhance Flagger Safety, *Transportation Research Record 1148*, Transportation Research Board, Washington, DC, pp. 34-37.

65. Kemper, W.J., H.S. Lum, and S.C. Tignor, "The Safety of Narrow Lanes for Traffic Control at Construction Site," *Institute of Transportation Engineers Journal*, 10(1), Washington, DC, January 1985, pp. 33-38.

66. Rouphail, N.M., Z.S. Yang, and Fazio, J., Comparative Study of Short- and Long-Term Urban Freeway Work Zones, *Transportation Research Record 1163*, Transportation Research Board, Washington, DC, January 1988, pp. 4-14.